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# THE JOURNAL

—OF THE—

# FRANKLIN INSTITUTE,

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DEVOTED TO

## SCIENCE AND THE MECHANIC ARTS,

PUBLISHED BY

## THE INSTITUTE,

UNDER THE DIRECTION OF THE COMMITTEE ON PUBLICATION.

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VOL. CXX.—Nos. 715-720.

THIRD SERIES.

VOL. XC.—JULY TO DECEMBER, 1885.

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PHILADELPHIA:
FRANKLIN INSTITUTE, NO. 15 SOUTH SEVENTH STREET.
1885.

# JOURNAL OF THE FRANKLIN INSTITUTE.

Vol. CXX.

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# JOURNAL

OF THE

# FRANKLIN INSTITUTE

OF THE STATE OF PENNSYLVANIA,

FOR THE PROMOTION OF THE MECHANIC ARTS.

VOL. CXX. JULY, 1885. No. 1.




## MILL ARCHITECTURE.*

BY C. JOHN HEXAMER.

The first principle in architecture, and foremost in buildings intended for manufacturing purposes, is utility; and all other considerations are subservient to it. The elements of Vitruvius—*firmitas*, *utilitas*, *venustas*, stability, utility, beauty—still hold good. That mill building is the best which is best suited for its purpose, and that architect is most expert, who exactly knows what changes in his plans are required for every department of manufacture. I, of course, do not mean to say that a mill should be erected in bad proportions "a hideous mass of stone, an eyesore to mankind;" on the contrary, an architect shows his superior skill if, notwithstanding the small amounts usually allotted to decorative purposes, and the fetters which that tyrant utility places on him, he is still able to erect an evenly proportioned, well-looking building. The higher a building is, the better should be its construction. The simplest of all rules of building, to construct a building safely and solidly, is frequently neglected. The great principle in fire constructions is to divide the building into numerous parts, and then to construct these parts in such a manner and of such a material that a fire originating in any one part may be restricted to it. The main great divisions into which a manufacturing place is divided are the stories.

* A lecture delivered before the Franklin Institute, December 17, 1884.

It becomes our problem then to construct each story so that a fire starting in one, may be restricted to that story; so that smoke, fire and water used to extinguish the flames, may not harm other stories and their contents. To arrive at this result there must be no openings in the floors; that is, the elevators and stairways must be outside of the main building, and belt and other openings must not break the floors. In order to accomplish this we must place stairways and elevators in separate stairway and elevator houses, the walls of which should be of sound brick and of sufficient thickness. The walls should only be broken by the doors leading into the separate stories. These doors should be iron-lined on both sides, and should be self-closing (either by a spring or weight) the doors being held open by a piece of fusible solder, which melts at any considerable rise of temperature.

The practice of putting in wooden sills, and lining them on top with sheet iron, is to be deprecated, as the woodwork of the adjoining floors forms a juncture with the wooden sill, and a fire will be transmitted underneath the iron. The elevator openings in the elevator house should be self-closing, so that a double security—the elevator doors and the doors leading into the main building—may be had. Especial care should be taken to extend the walls of the stairway and elevator house through the roof of the main building, thus cutting the trussing and timbering of the roofs, so that a fire may not be transmitted through the woodwork of the roof. A good-sized ventilator should be placed over the elevator house, so that in case of fire the smoke may escape through this—like a chimney—thus making it easier for firemen to see and work, and for employés to escape from the building; this is of so much importance that the Philadelphia Fire Underwriters' Tariff Association has made it a requirement in hotel buildings. Great care must be taken to keep the bottom of elevator houses free from waste and rubbish as these by igniting either spontaneously, or by a burning object being thrown into them, have caused many fires. The safest construction for a stairway house is that used at the Ontario Mills, of the Arrott Steam Power Mill Company, in which the stairway house is entirely cut off from the main mill by blank coped walls without any direct communication with the mill, the communication between the mill and the stairway house being effected by means of iron porches on the outside of every story.

## FLOORS.

The safest floor, which has for a long time been used in fire-proof construction, is one consisting of brick arches, sprung between iron girders. In order to be of practical value, the spans must not be too large, as iron, which is an excellent conductor, soon warps by unequal expansion in case of fire, and is apt to throw out the intervening arches. When spans are large, the intervening arches readily drop out of the girders which hold them, and thus entire buildings, which were considered fire-proof have been totally destroyed. Care must, therefore, be taken to cover all exposed iron surfaces with a poor conductor of heat.

A construction much used in France, which has proved successful in many cases, is an iron girder with concrete arches, the arches being formed by means of moulds and held together with tie rods until dry. When good concrete dries, it becomes as hard as stone, and being an excellent non-conductor of heat, when properly erected, so as to surround the entire iron work, keeps the iron from becoming heated and and warping.

Iron girders have also been used in conjunction with terra cotta, and with the so-called terra cotta lumber. Terra cotta lumber is a material manufactured from clay and saw-dust. The clay mixed with saw-dust, is formed into the required shape, then dried, and burned in a kiln; the organic part is destroyed, and a porous mass remains which may be worked with a chisel like lumber. Tests which have been made with this material in New York have proved very satisfactory.

[A number of slides were then shown, illustrating the manner in which these different materials are used and erected.]

A concrete floor, when made with good cement, is, next to a brick arched floor, the best known. This substance forms into one solid, hard, rock-like mass, and those who have seen the works in France, where entire churches and aqueducts have been built with it, can no longer doubt its efficiency. It may be well remembered how at the great fire of the Jayne building, in Philadelphia, an ordinary mortar floor saved the second story. The problem then is, "How can we construct a cheap, light and effectual floor?"

A solid three-inch plank floor, laid flat, tongued and grooved, with one and a quarter inch flooring boards on top arranged for flooding, is

the usual manner in which the floors of mills are now laid. These can be much improved if, between the plank and flooring boards, a layer of good mortar or concrete is inserted, making an excellent, slow burning floor. Asbestos paper, or better the thicker asbestos mill board, is sometimes used with good effect, between the flooring boards and plank; although it has been claimed by some that the asbestos is hygroscopic and attracts the moisture from the flooring, causing the boards to rot. I have never experimented to any extent with this material, and cannot therefore, express an opinion on its merits or demerits.

All floors should be arranged for flooding. This is accomplished by raising all sills and other openings through which water may escape. A floor arranged for flooding, when otherwise well laid, is one of the best means for restricting a fire from extending from one room to another, for, as soon as the fire appliances, such as sprinklers, hose, etc., are turned on, there is, in a very short time, a pond of an inch or an inch and a half deep formed on the floor, which prevents the floor from igniting; at the same time, a rise in temperature vaporizes the water on the floor, causing the formation of steam, which aids in extinguishing the fire.

We are now fairly well protected from fire, smoke and water from above, how then are we to protect the wooden ceiling in case of a fire from below? The simplest (but costly) method would be to iron-line all wood-work; another would be to cover the wood-work by a so-called fire-proof solution. I have experimented with all solutions which I could learn of; but as I have not time to go into details on this part of the subject I must refer you to a series of articles in the *Spectator* in which I have described the results of my experiments.

It is well known, that several preparations exist which render wood impervious to heat, and, at the same time, increase its durability. Some of the solutions have been tried on a large scale, and have proved themselves successful wherever used. Although these measures are cheap, and their success demonstrated, they have, with few exceptions, (as for example, at Frankfort-on-the-Main, the Hof Theater at Berlin, and several German manufactories), not been employed. Perhaps the general public will, in view of frequently recurring catastrophies, at last comprehend that even the retardation of the combustion of wood-work would be of inestimable value in securing immunity from fire, and that the spreading of flames will be greatly retarded if, instead of burning rapidly, as dry wood will, it slowly chars into coal.

The nature of wood makes it an easy matter to change it into a state frequently, though incorrectly, called fire-proofed. On account of its porosity, a solution applied to its surface sinks deeply into its pores, thereby attaining a firm hold, and on account of its rigidity exposes only the covering to abrasion. Care should be taken where such solutions have been used, to replenish them, from time to time, so as to keep the wood entirely covered.

Asbestos paint is a clean and excellent coating for wood, and still better, the thicker asbestos concrete. These substances act like true paints, adhere tightly to the wood, give protection against high temperatures, and do not readily rub or chip off. It has but one objection; that is, its solubility in water; it cannot be used in places exposed to the action of water, but for most interior purposes this is no material objection. Great care must be taken in purchasing this article and it should always be tested before being used, as much of the so-called "asbestos paint" which is sold is entirely worthless.

Ordinary whitewash is a cheap and excellent coating against fire. It adheres tightly to the wood, impregnating it to a certain depth, and, when frequently replenished will form an excellent protective coating.

Wood, impregnated with ammonium sulphate, transforms it into a condition which has frequently, but incorrectly been termed "fire-proof." Ammonium sulphate keeps the wood from burning with a flame, and only those parts which come in direct contact with fire are charred, but the parts in contact with flame, even in charring, will not transmit the fire any further. Numerous experiments which I have made with ammonium sulphate, have, in every instance, proved successful. At the severe fire of a large chemical works where parts of the wood impregnated with this substance, in direct contact with the flames, were charred, the adjacent parts remained intact.

When ceilings are plastered, this should be done with wire netting and the plaster laid on it, especial care being taken that the netting follows the outlines of the ceiling closely, so that no hollow spaces occur. The correct method is to avoid all hollow spaces, in which dirt may accumulate and fire travel. The so-called "sealed" ceilings, that were formerly in vogue, should always be avoided.

## GIRDERS.

Girders should be solid. When it is necessary to use compound girders, they should be tightly bolted together, so as to leave no inter-

vening spaces. In storehouses, etc., where there is but little vibration, girders may be inserted in the wall by placing them either on brackets or a short distance into the wall, with bevelled edges, without any further anchoring. In mills, where the amount of vibration is great, Woodbury advises to securely bind the beam to the wall by embedding in the masonry a flat cast-iron plate with a transverse fin upon each side near the end, one to secure the plate in the wall and the other in a groove across the under side of the beam, firmly secured by wedges driven in at each side of the fin. The bricks in the wall for about five courses above the beam should be laid dry, and the upper edge of the beam at the end slightly rounded, and an air space should be provided at each side of the beams.

Under no consideration should the old-fashioned anchorage of fastening the girder on the outside of the wall with a large anchor plate be used, as when the beams burn through, the leverage brought to bear on the wall will overturn it.

[Numerous slides were here shown, illustrating the different modes of anchorage and the construction of girders.]

## WALLS.

Brick is the best material for fire construction. It stands long after granite has disintegrated and marble has been burnt into lime. Iron fronts are to be deprecated, and especially such shells of iron as are frequently erected, without even a brick filling. Sandstones, when the sand particles are held together by a good binding material are serviceable, but those in which the sand particles are held together by lime should not be used in building. Granite is a very poor stone for fire construction, as its inter-molecular spaces contain water, which, on being heated vaporizes into steam, causing the disintegration of the stone. Marble is also a poor material to use, as, on becoming heated, it is decomposed, carbonic acid and burnt lime being formed. For this reason, lintels over doors, windows, etc., should never be made of marble, granite, or poor sandstones. Preferably, a brick arch should be sprung. Good brick buildings have frequently been destroyed by having poor stone lintels over driveways and so on, which were destroyed by fire, causing the falling of the brick wall. Where further ornamentation is required, terra-cotta ornaments may be used; these are now manufactured in all shapes and varieties.

### CORNICES.

Where cornices are used, these should be of brick or terra-cotta. Under no circumstances should "wood-boxed" cornices be used, as these transmit the fire from one part of the building to the other, and for this reason, even hollow metal cornices are objectionable, as they form flues along which the flames travel.

### COLUMNS.

The best column to stand in case of fire is a good hard wood column, without taper, bored near the top and bottom so as to prevent dry rot, lined with sheet iron or any other metal, or covered with a good protecting substance. Of all columns, those of exposed cast iron are the poorest. These, on even a slight rise of temperature, readily disintegrate, especially when water is poured upon them. Wrought iron, on being exposed to high temperatures, expands and warps. Exposed iron, therefore, is the most untrustworthy of all materials for column construction.

In order to protect iron columns from surrounding temperatures numerous plans have been devised to cover them with non-conductors. The columns constructed by Mr. Wight, of Chicago, are excellent for this purpose. Terra-cotta lumber has been used for this purpose, as well as plaster and mortar. Ordinary lime mortar or concrete is preferable to a gypsum composition, as this readily corrodes the iron. Care must be taken to surround all parts of columns exposed to abrasion, the base should have a hood of wood.

[Numerous illustrations of improved columns were then shown.]

### ROOFS.

There is no part of a building which is put to such a severe wear and strain as the roof; being, at certain times of the year, exposed to high temperatures on the inside, and to very low temperatures on the outside. A good roof should be of three inch plank, tightly fastened together, protected on the inside with sheet iron or other metal, asbestos concrete, or with a wire netting tightly fastened on, so as to leave no hollow spaces, and the plastering placed on this; a good metal covering being placed on the outside with nails counter-sunk and stopped with putty. Slate makes a poor covering, as by a rise in temperature it readily disintegrates.

## FIRE DOORS.

There are few parts in fire construction which are of so much importance, and generally so little understood, as fire doors. Instances of the faulty construction of these, even by good builders and architects, may daily be seen. Iron doors over wooden sills, with the flooring boards extending through from one building to the other, are common occurrences. We frequently find otherwise good doors hung on to wooden jambs by ordinary screws. Sliding doors are frequently hung on to wood work, and all attachments are frequently so arranged that they would be in a very short time destroyed by fire, and cause the door to fall. In case of fire, a solid iron door offers no resistance to warping. In an iron-lined door, on the contrary, the tendency of the sheet iron, to warp, is resisted by the interior wood, and when this burns into charcoal, it still resists all warping tendencies. I have seen even heavily braced solid iron doors warped and turned after a fire, having proved themselves utterly worthless. It is needless to say that when wooden doors are lined, they should be lined on both sides; but frequently we find so-called fire-proof doors lined on one side only.

Good doors are frequently blocked up with stock and other material, so that in case of fire they could not be closed without great exertion, or they have been allowed to get out of order, so that in case of fire they are useless. This has been so common that it has given rise to the jocular expression of insurance men, when they are told that a fire door exists between two buildings, "Warranted to be open in case of fire." The strictest regulations should exist in regard to closing the fire doors nightly. Frequently we find that although the fire door, and its different parts, are correctly made, there are other openings in the wall which would allow the fire to travel from one building to the other, such as unprotected belt- and shaft-holes. That a fire door may be effective, it must be hung to the only opening in the wall.

The greatest care must be exercised to keep joists from extending too far into the wall, so as not to touch the joists of the adjacent building, which would transmit the flames from one building to the other in case of fire. A good stone sill should be placed under the door, and the floor thereby entirely cut. Sills should be raised about one and a half inches above the level of the floor, in order to accomplish the necessary flooding of the same. If stock must be wheeled from one building to the other, the sill can readily be beveled on both sides of

the wall, allowing the wheels to pass readily over it. Lintels should consist of good brick arches. When swinging doors are used, they should be hung on good iron staples, well walled into the masonry, and the staples so arranged that the door will have a tendency to close by its own weight. The door should consist of two layers of good one and a quarter inch boards, nailed crosswise, well nailed together and braced, and then covered with sheet iron nailed on, or if of sheet tin, flanged, soldered and nailed. Particular care should be taken to insert plenty of nails, not only along the edge of the door, but crosswise in all directions. I have seen cases, in which nails had only been placed along the edges, where the entire covering had been ripped off through the warping tendencies of the sheet iron.

The hinges on these doors should be good strap hinges, tightly fastened to the door by bolts extending through it, and secured by nuts on the other side. Good latches, which keep the door in position when closed, should always be provided. In no case should the door be provided with a spring lock, which cannot be freely opened, as employés might thereby be confined in a burning room.

Sliding doors should be hung on good wrought iron run-ways, fastened tightly into the wall. Wooden run-ways, iron lined, which we frequently see, are not good, as the charring of the wood in the interior causes them to weaken and the doors to drop. Run-ways should be on an incline, so that the door when not held open will close of itself. Care must be taken to have a stop provided in the run-way, so that the doors may not, as I have frequently seen them, overrun the opening which it is to protect. Doors should overlap the edges of the openings on all sides. Large projecting jambs should never be used.

All doors contained in "fire-walls" should have springs or weights attached to them, so as to be at all times closed. Fire doors can be shut automatically by a weight, which is released by the melting of a piece of very fusible solder employed for this purpose. So sensitive is this solder that a fire door has been made to shut by holding a lamp some distance beneath the soldered link and holding an open handkerchief between the lamp and link. Though the handkerchief was not charred, hot air enough had reached the metal to fuse the solder and allow the apparatus to start into operation.

These solders are alloys more fusible than the most fusible of their component metals. A few of them are—Wood's alloy, consisting of:

| | |
|---|---|
| Cadmium | 1 to 2 parts. |
| Tin | 2 " |
| Lead | 4 " |
| Bismuth | 7 to 8 " |

This alloy is fusible between 150° and 159° Fahr. The fusible metal of d'Arcet is composed of:

| | |
|---|---|
| Bismuth | 8 parts. |
| Lead | 5 " |
| Tin | 3 " |

It melts at 173·3°. We can, therefore, by proper mixture, form a solder which will melt at any desirable temperature.

Numerous devices for closing doors automatically have been con-constructed, all depending upon the use of the fusible solder catch. catch.

[Various automatic doors were then explained with the aid of stereopticon views.]

### CONSTRUCTION OF PICKER-HOUSES.

The proper construction of that hazardous part of a mill, the picker-house, is of the utmost importance. Frequently we find picker-houses, otherwise well constructed, with some fault which endangers the whole structure. Glass transoms above iron doors, between the main mill and the picker-house, may sometimes be seen, while large belt holes in the protecting wall are very common. These will readily convey fire from the picker-room to the mill. It is difficult to protect belt openings by iron slides. It is therefore better to have power conveyed from the mill to the picker-room by means of shafting. When journal-boxes are set in the wall, small apertures only are required.

A frequent mistake in picker-houses is to leave the windows in the wall of the main mill above the picker-house, unprotected by iron or iron-lined shutters. Picker-houses are generally one story high, and the flames striking upwards are thereby communicated to the mill. The ventilators and skylights in the roof of the picker-house increase the danger from these sources. Windows in the picker-house, facing the mill, may also frequently be found. These, if possible, should be dispensed with. If they are absolutely necessary, good iron-lined shutters should be provided, which should in all cases be arranged to close from the outside. Frequently, enclosed gangways connect the picker-

house with the main mill. These should be constructed of corrugated iron, with good iron-lined doors at both ends. If these are not arranged to close automatically in case of fire, they should be so fixed that they may be closed from the outside without entering the gangway. A great mistake, frequently made, is to store stock in the gangway, or to allow waste and other rubbish to accumulate in the same. In case of fire, this may act as a conductor for the flames to extend from one building into the other, before the opportunity is seized to close the fire doors.

Brick, stone or cement, floors should be used in the picker-house. Wooden window-jambs and casings should not be used; while substantial iron, or, better still, iron-lined shutters (for solid iron shutters have the demerits of iron doors) should be hung over all openings, extending beyond the edges of the windows. A shutter should be constructed like an iron door, hung on good iron staples built into the wall, and always on the outside of the building. Shutters hung on wooden window casings will, of course, fall as soon as the wood-work is destroyed. Iron shutters should never be placed on the inside, as it is absurd to expect that anyone will remain inside of a burning building to close shutters.

### CARD-ROOMS.

The card-room should be as large and as well ventilated as possible. The ceilings should be high, and should contain as few projections as possible, as these will cause the "fly" to settle on them. The card-room should be wide enough to allow the placing of the cards in sets side by side, with sufficient space between the sets to allow the cleaner to pass freely around them.

### TRANSMISSION OF POWER.

All driving fixtures should be contained in separate houses, constructed like a stairway or elevator-house, cut off from the mill by coped fire walls, as a fire will be carried from story to story through belt openings and boxes. Particular attention should be given to belt boxes, where they are used, to keep them at all times scrupulously clean from waste fly and so on. Belt boxes should be provided with a good supply of automatic sprinklers. Objections have been raised to sprinklers by some, for the reason that should they be opened by accident, the belts would be damaged by water. Mr. Edward Atkinson has suggested that the belts be enclosed in a glass chamber, and

that automatic sprinklers should be placed outside of the glass. This arrangement, I understand, has worked well in practice.

All dangerous journals throughout a mill should be provided with automatic alarms, which give a signal as soon as a journal becomes dangerously hot. One of the best, the Journal Thermostat of Whitaker, consists of a U-shaped glass tube, with arms of equal length, one of which is closed. The left arm contains a small amount of a volatile liquid hydro-carbon, and the remainder is filled with mercury. When the temperature of the journal rises beyond a certain point, the hydro-carbon is vaporized, and forces out the mercury, which, in collecting in the receptacle below, closes an electric circuit, which gives the alarm.

[Various slides were shown for further illustration.]

## HEATING.

The old primitive method of heating by stoves is rarely found in the better class of mills. Where these are used, care should be taken that they are placed on metal, with good stove pipes, passing into chimneys, the stove-pipes being tightly wedged into the wall, so as to keep them from disengaging and allowing sparks to fall into the room. Under no consideration should stove-pipes pass out of windows.

The safest system of heating is by hot water. In this case, the heat is produced by radiation from pipes filled with hot water, the same being heated in a boiler, preferably outside of the mill.

Steam is usually employed for heating in mills. Special care should be taken to have the pipes free from wood-work, and away from all places where dust, dirt, waste, etc., may accumulate. Steam pipes should be hung along the ceiling, about 24 inches below it, in preference to the old fashion, along the sides of the room, where stock and waste are frequently piled. The theory, so frequently advanced, that, if pipes be hung below the ceiling, the same amount of heat cannot be obtained as when they are hung along the sides, is erroneous. The following table, which shows the results of a series of experiments made by Mr. C. J. H. Woodbury, demonstrates this fact.

Hourly thermometrical observations were taken in a room, 75 x 400 feet, supplied with five rows of steam pipes, against the walls near the floor, in the first instance; and in the second there were four rows of pipe around the room, two feet from the walls and hung the same dis-

tance below the ceiling, requiring only three-quarters as much pipe as in the first instance.

*Mean Temperature by Hourly Readings.*

| Thermometers hung in centre of room. | Degrees Fahrenheit. | |
|---|---|---|
| | Pipes at side. Dec. 29 to Jan. 5. | Pipes elevated. Jan. 29 to Feb. 5. |
| Sixteen inches from ceiling | 80·05° | 80·80° |
| Midway | 76·52° | 76·90° |
| Sixteen inches from floor | 77·08° | 77·00° |
| Average | 77·88° | 78·23° |

The reasons why steam pipes ignite wood are twofold. First, in the case of superheated steam, we have a regular combustion going on; in the second case, with steam pipes containing steam, at the usual temperature, we have a secondary phenomenon of spontaneous combustion. In the latter case, the steam pipes slowly dry the wood, the contained moisture being vaporized, and at last the wood assumes a state resembling that of charcoal; when in this condition, combustion may take place spontaneously.

At a discussion before the French Academy, in 1879, this was brought out clearly. M. Cosson described an accident which had occurred in his laboratory a few days before. While the narrator was working in the laboratory, a portion of the boarding of the floor spontaneously took fire. The boards were in the vicinity of an air-hole, fed with warm air from a stove four metres away on the floor below. A similar accident had occurred two years ago, and in consequence M. Cosson had the boards adjoining the air-hole replaced by a slab of marble. The boards which now ignited adjoined the marble. The heat to which the boards were subjected was, however, very moderate, being only that of air at 25°C. (77°F.) Nevertheless, M. Cosson said the wood had undoubtedly been slowly carbonized. Being thus rendered extremely porous, a rapid absorption of the oxygen of the atmosphere had resulted and sufficient heat was thereupon produced to originate combustion. The danger thus disclosed, said M. Cosson, is one to which the attention of builders ought to be directed. In the instance in question, M. Cosson was able to extinguish the fire with a little

water, as he was present and witnessed its beginning; but had it occurred at night, during his absence, it would undoubtedly have completed its work of destruction. M. Fayé stated that at Passy, a few days before, a similar case of spontaneous fire, due to the action of the warmth from the air-hole of a stove upon the wood-work, had occurred at the house of one of his friends.

Mr. C. C. Hine, editor of the *Monitor*, relates the following: "The Institute of Technology, at Boston, long ago decided upon the danger of steam pipes passing through, and in contact with, wood. It was shown that the wood, by being constantly heated, assumes the condition, to a greater or less degree, of fine charcoal, a condition highly favorable to spontaneous combustion. This is so important and interesting a point that we may be pardoned for enlarging upon it somewhat, in contrast to the brevity of the foregoing paragraphs.

"Steam was generated in an ordinary boiler and was conveyed therefrom in pipes which passed through a furnace and thence into retorts for the purpose of distilling petroleum. Here the pipes formed extensive coils and then passed out, terminating at a valve outside the building. To prevent the steam, when blown off, from disintegrating the mortar in an opposite wall, some boards were set up to receive the force of the discharge, and as often as the superheated steam was blown against them, the boards were set on fire! This occurred in an oil refinery in Pittsburgh, Pennyslvania.

"Some years since, while on a visit to an Institution for the Deaf and Dumb, in Illinois, of which an esteemed friend is principal, we called attention to the manner in which some steam coils were secured to wooden supports, and pronounced them unsafe. They were shown to be a thousand feet or so—as the pipes ran—from the boiler, and our caution only provoked a smile. The next year we visited as usual, and, upon taking the principal's hand, he said—before exchanging salutations or inquiries—'Come with me, I wish to show you something,' and led the way to the room where, a year ago, his attention had been called to the steam pipe. 'There,' said he, 'examine that; I have been saving it for you since last winter; the coil fell down, and investigation showed that the screws had let go because the wood had been turned to charcoal and had no more strength to hold them.' The experience was new to him, it may be old to some of our readers, but its introduction here will illustrate a fact which is now becoming an admitted one among those who have given this matter attention.

"An experiment illustrating the effects of superheated steam was tried as follows: Steam was taken from an ordinary boiler through a pipe forty feet long. Ten feet from the farther end a collar of wood was fitted closely to the pipe; ten feet near the boiler a lighted kerosene lamp was placed under the pipe. In ten minutes the wooden collar was on fire."

LIGHTING.

Numerous fires have been caused by lamps in mills. These should be constructed of metal, and not of glass, as the latter readily breaks High-test oils only, with a flash point of 150 degrees or over should be used.

The watchman should burn lard oil in his lamp, which is safer than mineral oil. In order that he may not, by trimming his lamp in the mill, cause fires, as has been the case, it should be inclosed and provided with a lock and key, the key being fastened in some fire-proof room in the building, so that when the lamp burns poorly, the watchman will have to return to the fire-proof room and trim and fix his lamp there, and not in the mill among the loose stock and material.

In order to increase the safety of lamps, so-called safety lamps have been invented. These are glass lamps inclosed in metal cases, which protect the glass receptacle from breaking. Westland's lamp has, experimentally, proved successful, although I have no further evidence of how it has worked in practice. This consists of a globe of glass, containing the oil, surrounded by a concentric sphere, containing water charged with carbonic acid gas under pressure. As soon, therefore, as the lamp is broken, carbonic acid gas is set free and the flames extinguished.

Gas is the general material yet used for illumination. Gas lights should be inclosed so as to keep stock from falling into the flames, and from igniting fine particles of dust and "fly" in card- and picker-rooms. Especial care should be taken to clean the tops of enclosed gas lights well before lighting up, as many fires have been caused from dirty inclosed lanterns. In order to safely light up gas lights, several devices have been constructed, among which are Mr. Whiting's electric torch, in which the gas is lighted by means of an electric spark. Another is a German device of Bodmer, by means of which an enclosed torch is pressed down over the gas jet and the gas in escaping is lighted.

[Several of these devices were then shown with the aid of projections on the screen.]

Gasoline vapor, or as it is frequently called, gasoline gas, is sometimes used. Where gasoline machines are used, the machines, especially the carburetting arrangement, should be placed at least fifty feet from all other buildings. The gas machine building should be on a piece of ground lower than the other buildings, so that the gasoline vapor which may escape, and which is heavier than air, may flow away from the buildings. Care must be taken to have all supply pipes descend towards the machine building, so that any vapor which may have condensed in its passage from the carburetter of the mill may flow back into the carburetter. Care should be taken to have a drip-cock attached to every jet, so that the pipes may be well emptied of gasoline before lighting the vapor. Gasoline vapor is extremely explosive and dangerous.

Of late an excellent gaslight has been introduced, the so-called Siemens Regenerative Burner. Care should be taken where these are erected, to have the ventilating flues, which carry off the products of combustion, well constructed of metal, free from wood-work, as these lamps give off a great amount of heat, and readily ignite wood-work which is in contact with the ventilating flue.

The electric light is daily coming more into use, and when properly installed is very safe. Daily tests should be made for grounds. Great care should be taken to have all wires properly insulated, all connections in wires well made, the proper amount of cut-outs, switches and safety catches, provided, and where arc lights are used, proper care taken of the glowing carbon points, which, in falling, have caused fires. One of the greatest hazards is caused by improper insulation, as moisture will cause an electric current to pass from one wire to another, especially through water which contains salts, such as lime, which it dissolves in passing through ceilings or walls.

[Numerous illustrations of electric lights were shown, showing their hazards and how they may be safely installed.]

### FRICTIONAL ELECTRICITY.

Electricity is frequently caused by the friction of belts on pulleys, a fact known in Germany for a long time, but first described in our country, I believe, by Mr. F. W. Whiting. This has been the cause of fires and

should be guarded against by connecting all parts on which the electricity accumulates, with the ground, by means of wires attached to the object and to a gas-, or preferably, a water-pipe. This is one of the most prolific sources of fires in the heavy coating rooms of oil-cloth factories, as the electric sparks readily ignite the benzine vapors present. In one of the largest Philadelphia works of this kind, the iron receiving racks were so charged with electricity that long sparks could be drawn from them, but since they have been properly "wired," not a trace of electricity is left in them.

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## THE FUTURE WATER SUPPLY OF PHILADELPHIA.*

BY COL. WILLIAM LUDLOW,
Chief Engineer of the Philadelphia Water Department.

Vice-President FREDERICK GRAFF, introduced COL. LUDLOW, who spoke as follows:

MR. PRESIDENT, LADIES AND GENTLEMEN:—I must admit that I am somewhat taken by surprise when I received the invitation from the very excellent Secretary of the Institute, requesting me to attend the meeting to-night and make some remarks regarding the future supply of the city; I was under the impression that the meeting would resolve itself into an informal professional discussion of the matter, but I find that I am to have the field somewhat to myself and to talk to more people than I had anticipated. I know, however, that you are all interested in the subject as well as I, but I have not prepared any formal address and shall confine myself, therefore, to general remarks as to the present aspect of the important question of the future water supply of this city.

The subject is not new. I think my friend, the President, will admit that it was an old one in his early days, and it has so continued to the present. Agitation of the subject has continued for a generation past without definite conclusions being reached although we are approaching more and more closely to the necessity for reaching a decision. This futility of discussion has resulted mainly from the

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* Abstract of remarks presented at the Stated Meeting of the Franklin Institute, held Wednesday, April 15th, 1885.

absence of full and accurate investigation of the real facts upon which alone a reliable and final judgment can be made. The situation is about this: Philadelphia is a city happily situated in many respects, with a great river on either side; one stream, the Schuylkill, drains a mountain region and has been looked to both to supply the water needed for municipal purposes, and even to furnish the power by which that supply should be pumped and delivered to the citizens. Hence the construction of those early water works at Fairmount, originally breast wheels, which were later converted into turbines and which have continued in service to the present day. With the growth of the city came the necessity for an increase of quantity, and from time to time the appliances for augmenting the daily pumpage have been multiplied until now there are no fewer than eleven engines at four great pumping stations drawing from the Schuylkill river into which, to a considerable extent, the waste matters of the valley are poured. On the other side of the city is a great tidal stream which receives the waste matters of the community, and at two points upon the Delaware we have been drawing these waters to supply the districts of Kensington and Frankford, but it has long been recognized that the water pumped at Kensington contained matters prejudicial to health, and the quantity of this was increasing year by year; this station has therefore been abandoned. The serious thought of those who from time to time have been charged with or interested in this vital matter of Water Supply have been turned to the consideration of the means of amending the defects of quality and quantity. There are two sources whence the city of Philadelphia can take its water, I mean practical sources as determined by engineering considerations; namely, the valley of the Schuylkill and the valley of the Delaware. The problem to be solved is whence a suitable supply both in quality and quantity can be derived to the best advantage; namely, at the lowest cost of construction and the lowest future cost of maintenance. A gravity supply is advantageous when practicable, for the reason that the water intercepted at a sufficient elevation will pass from its source to the city through the conduits, as water will flow down hill, whereas the raising of the large quantity of water required for the supply of the city involves heavy expenditure for machinery, and a constant annual charge for fuel and service.

For two years past the Department with which I have the honor to be connected, has assiduously sought to gather all the information

bearing upon this matter which was attainable by topographical and hydrographical surveys, by meteorological observations, by chemical analyses and by sanitary inspections, endeavoring to cover the entire field within which lay facts pertinent and important. Our observations are drawing to a close. About nine-tenths of the field of exploration have been covered, and I trust that within another year we shall be enabled to complete and digest the information so gathered and present to the city, and to the engineering world the results of our labor in complete shape. It was for lack of this information that previous investigations have been rendered futile. The most important report which has been made upon this subject was presented about ten yeears ago, in 1875, when in anticipation of the celebration of the Centennial, a commission of eminent engineers was gathered to consider the entire subject, taking into account both the condition of the present supply and what should be done for the future. That their report, containing most valuable information, should have resulted in inaction is largely attributable to the fact that they were without the necessary exact data for final judgment. They made the best recommendations which, under the circumstances, could have been formulated, but in the light of fuller information it is neceasary to differ in some respects from the preliminary conclusion which they reached.

At present I cannot say that I am prepared to announce final conclusions as to the general solution, but it appears to lie in the choice of two projects.

Many years ago Mr. Birkinbine, who was then the Chief Engineer of the Water Department, proposed to secure a suitable gravity supply by impounding the waters of the Perkiomen Creek, the most important affluent of the Schuylkill river, which, from the supposed ample flow and purity of its drainage promised to be satisfactory and sufficient. The project contemplated the construction of a high dam near Schwencksville where the valley was narrowed and the rocky banks afforded a suitable site for a construction of this kind, and the Commission of 1875 were inclined, upon the data at their disposal, to favor this project, especially as the estimates of cost of a supply from the Delaware were vastly greater. Were we sure of ample amount and good quality, the Perkiomen project would present undoubted advantages of a high order. Unfortunately our investigations tend to show that the flow of the stream, even aided by gathering the waters of some of its affluents, is insufficient for the total quantity that Phila-

delphia will require in the near future. The Delaware project had never been carefully investigated, and for this reason: in 1883 two parties were formed, one to run a conduit line to the Perkiomen and elaborate the necessary information; the second party to run a corresponding line northward to the Delaware with the view of extending the investigation to near the Water Gap, at some elevation which should be found sufficient to permit the river to flow into the conduit and thence into the city, and the apparent probability of the insufficiency of the Perkiomen gave greater weight to the Delaware project than it had hitherto borne.

In considering the route toward the Gap, an examination of the map showed that an elevated region, designated as the South Mountain, stretching from northeast to southwest, lay across the Peninsula between the two rivers and would bar the construction of an aqueduct without extensive tunneling. A line northward from the city to the Delaware river reaches that stream at a point just below the gorge of the South Mountain, and a practicable conduit line upward could thence be made by following the valley of the stream, and thus evade the formidable obstruction which the mountain presents. Pursuing this plan, the surveyors were pleased to find, in the first place, an unexpectedly favorable line to the Delaware at Point Pleasant, half-way between Trenton and Easton, and the analysis of the water of the Delaware at this point further proved that in quality it was little inferior to the noted waters of the Gap itself.

This was our discovery. Furthermore, in proceeding northward from Philadelphia the conduit line crosses the valleys of several creeks of considerable volume—the Perkiomen, the two Neshaminies and the Tohickon—the latter stream discharging into the Delaware at Point Pleasant. The thought at once suggested itself that by utilizing the flow of these streams they could be intercepted, turned into the conduit and sent to the city by gravity, and that for a greater portion of the year the flow of these would be sufficient to supply all requirements, and that for such time as this flow should be deficient it could be made up by pumping from the Delaware itself. This, practically, constitutes a new project as compared with that of drawing water from the Gap entirely by gravity, and the expense of this construction was moderate enough to bear comparison with the Perkiomen project. It was found, for example, that the distance, in each case, was about the same, namely, thirty miles, and that the cost of construction was also

about the same, namely from $6,500,000 to $7,000,000. This estimate, you will understand, is that of the cost of the construction of the conduit merely, without adding other items (which will no doubt be large), for dams, land damages and other contingent expenses.

These conduits, I might say, are designed to be twelve feet in diameter with a grade of one foot in six thousand and with a capacity of delivering to the city 210,000,000 gallons a day at an elevation of 166 feet above city datum. This elevation is that of the existing Wentz Farm Reservoir, on the county line northwest from Bridesburg, and of the proposed Cambria Reservoir in the upper portion of the Twenty-eighth Ward.

With regard to this question of quantity, the following considerations present themselves: Our present pumpage is about 70,000,000 gallons a day, with a population approximating closely to a million people. A generation hence Philadelphia will contain two millions of inhabitants. The supply must therefore be doubled which would make it about 150,000,000 gallons a day. Furthermore, allowance must be made for the fact that in a large community like ours the use of water for the multiplied purposes of manufacturing and domestic uses increases in a greater ratio than the population itself. With works of the magnitude and cost of these which we have been discussing, it would be folly to project for a smaller supply than will be required within a generation, and for this reason 200,000,000 or 210,000,000 gallons were estimated for and the dimensions and grade of the conduit were thence determined.

Going back now to the question of distance and cost it will be seen that exact observation proves that for the first time the two projects, the Perkiomen and the Delaware, began to balance each other, and should the Perkiomen prove insufficient the Delaware project would practically stand alone; but in order that all possible ground should be explored I directed the examination of the upper Lehigh, a stream with which I was personally familiar from frequent journeys over the mountains to the Susquehanna Valley, and which, although so distant, possessed favorable characteristics from the purity of its water and the great elevation of its water shed. When, therefore, the Perkiomen proved of doubtful adequacy, the acute suggestion was made by Mr. Hering, who in a most thorough and capable manner has had immediate charge of these serveys, that were a sufficient amount of the waters of

the upper Lehigh brought into the upper valley of the Perkiomen a most excellent supply could thereby be secured.

You will observe that in all this matter the question of quantity has been of vital importance. We want 210,000,000 gallons a day. Now the low-water flow of the Delaware at the Water Gap in 1883 at a time when the stream was lower than it had been within the memory of the oldest inhabitant, was gauged and its flow at that time found to be about 700,000,000 gallons of most excellent quality. At Point Pleasant the volume of the river is about one-third greater than this, and in quality nearly as good as at the Gap. The Lehigh has a moderate flow. Its minimum in 1883 being about 70,000,000 gallons, but with excellent facilities for storing water at a great elevation above the reach of pollution. The bringing of this down into the upper valley of the Perkiomen would double its supply and the combination would once more have the prestige of a practicable and promising project.

At present, therefore, these two projects lie before us for consideration and ultimate decision, and, as I said before, within another year I trust that the problem will have been solved.

It may be of interest to explain how it happens that with the Schuylkill flowing past our doors all the engineers who have studied this subject seem to have concluded that at some time or other the Schuylkill River itself must be abandoned as a source of water supply. The reasons are these: The origin of the Schuylkill is in the mountains among the coal mines. The drainage from the coal measures, supplemented by the large amount of pumping from these mines constitutes a volume of acid water which fills the upper portions of the stream and is unfit either for drinking or manufacturing purposes, or even to sustain life. No fish can exist in it, nor can human beings drink it. In the course of its flow downward the Schuylkill above Reading traverses a geological belt of limestone whence considerable affluents feed the river, bringing with them a solution of the lime and the alkaline waters mingling with the acid waters of the parent stream neutralize each other and become again fit for ordinary purposes and for the existence of fish. Thereafter we have no further difficulty in this respect; that is with regard to the chemical characteristics of the water. The water as it reaches Fairmount Dam is sometimes slightly acid, sometimes slightly alkiline and sometimes neutral. But the important fact remains to be noted that the valley through its length is a populated district from end to end, and into it are poured all the waste matters of a large and busy

population; every town and industry contributing its quota of pollution, whether sewage or the waste products of manufacturing establishments. With two great railroads extending up its banks and with communities and towns increasing year by year in number and population, the Schuylkill can be described only as an industrial valley which in the future will be densely populated, and it becomes manifest at once that unless extensive engineering constructions be planned, strict legislative enactments be passed and rigid enforcement of these laws be insured, the waters of the Schuylkill must continue to receive deleterious matters in constantly increasing quantities, and that ultimately they will cease to be available for the purposes of that great city which lies at its mouth and absorbs the contaminations of everything above.

The population of the valley above Philadelphia, at present, is in excess of 350,000, and if we are to endeavor to protect the stream from this pollution, which is not only nauseous in contemplation, but in fact dangerous to health, sewers must be built upon both banks which shall intercept and discharge all waste matters and convey them down the entire length of the valley until they can be discharged into the Delaware River below the city.

Another important fact must be observed; within sixty years a marked diminution has taken place in the minimum flow of the stream.

Sixty years ago the summer flow of the Schuylkill was estimated at 500,000,000 gallons a day. Successive estimations of the low-water flow were made from time to time, all showing a diminution in quantity until that in 1874 determined the minimum flow as 250,000,000 gallons.

Here, then, within this period the low-water flow of the stream had decreased one-half, and, supposing that it had gone no further than was observed at the last examination, the flow of the stream when at its low stage is little more than the city will require a generation hence. It follows that with but a slight shrinkage comparatively, in the future the city would be pumping up the entire river. I do not wish to be misunderstood with regard to this, and therefore beg to explain what I mean by the minimum flow: It is not probable that the total annual flow of the Schuylkill has decreased. This flow is dependent upon the rainfall, and cannot in the absence of any marked changes in the rainfall be itself materially modified, but the destruction of the forests in its head-waters, the clearing and cultivation of lands, have to a great extent deprived the river of that power of conservation which belongs

to wood land, whereby the rainfall is held back and checked, as it were, in its passage to the stream, and the flow is more nearly equalized and prevented from dashing down and passing out. With the removal of the forests this fact ensues: The rainfall rapidly descends to the stream, creating a freshet which sweeps down the valley and passes out and is lost. During periods of drought, the rains being suspended the river shrinks, its flow becomes moderate and its movement gentle, and presently we attain the minimum discharge.

In depending upon a stream, without taking means to restrain the passage of freshets, it is manifest that we can pump no more from the river than it will daily bring to us, and the minimum flow therefore should be as carefully investigated as we would investigate the strength of the weakest link in a chain from which we intend to support a weight.

It would be possible by means of dams across the stream to impound some portion of the volume of these successive freshets until the periods of drought, which occur always in summer and frequently in winter, and to draw upon these reservoirs when required. But again that question of the pollution of the stream comes in, occasioning doubt as to whether should this be done, it might not be found in the end that large expenditures had been wasted by reason of the inferior quality of the water and the injudiciousness, of depending in perpetuity upon it. For the reasons given the water varies greatly from time to time in its chemical character, potability and wholesomeness. At times during the passage, for example, of the freshets the waters of the stream being largely the results of recent rainfall, are in good condition; at other times they are highly charged with pollution and occasionally get themselves into a condition of the most nauseous offensiveness. It is manifest that unless these difficulties can be amended the Schuylkill cannot continue to be regarded as a suitable supply for a population like this, and the vital importance to modern communities of a bountiful supply of wholesome water for all purposes is so great as to constitute one of the most serious problems relating to municipal existence, and sooner or later there is not a city in the world that has not this important matter to decide.

I have endeavored to present to you briefly the aspects of the problem precisely as they present themselves to-day. It is one in which every individual is in the highest degree interested. It is one upon which the future prosperity and welfare of this city depend.

I am very much obliged to you for your attention, and trust that some one will take up the discussion at this point.

DISCUSSION.

PROF. HOUSTON.—The exceedingly interesting remarks the gentleman has just made are enough to give thoughtful people considerable matter for reflection. The question of the water supply of any great city must always be a difficult one to solve, since as the needs for an increased amount of water grow, the ability of the ordinary means to give a large supply of pure water decrease. The rivers of any country are the natural sewers into which the dirt and filth of that country drain; and to safely take the water supply of a large city from any river requires considerable thought and skill.

The problem as to the water supply of the city of Philadelphia is one to which we have all given considerable attention. A number of years ago, I called the attention of the Franklin Institute to what I regarded as a dangerous pollution of the Schuylkill River; and I am glad to hear Col. Ludlow speak in such plain and unmistakable language concerning the probabilities of the near future of the Schuylkill. I take it that the real danger coming from drinking Schuylkill water does not exist with equal gravity all the year. During a large part of the year the lower basin of the Schuylkill, from which most of our city's supply is taken, is practically in the condition of a "steppe-lake," that is a river without an outlet.

Under these conditions, its impurity increases from the loss of pure water by evaporation. For many months in the year, the citizens of Philadelphia know that comparatively little or no water goes over the dam, and were it not for the water which goes through the locks, there would be no discharge at all except that which is pumped into our reservoirs. Under these conditions, we are actually damming up the river and drinking its contents. During many months in the year, and particularly those months when we should be the most careful of the purity of our drinking water, we are drinking something that is far from wholesome. I have not the slightest hesitation in expressing this as my opinion. During this time of the year, from a water itself impure, we pass off a large quantity of pure water by evaporation, and drink the dregs. Now we do not want the dregs of the Schuylkill, especially when in the immediate neighborhood of our pumping stations we have the outlets of sewers.

Of course, Schuylkill water cannot be as poisonous as many allege, else we would not be here. The main point, in my mind, is: Can we rely on the Schuylkill for our water supply in the near future, say for the next fifteen or twenty years? Col. Ludlow has stated the problem very clearly. The very conditions of the valley of the Schuylkill seems to render it improbable that we can continue using the water for drinking purposes.

The destruction of the forests over the upper basin of the Schuylkill, unquestionably favors the rapid drainage of the rain water; so that, for a considerable part of the year, we have so limited a supply that, as has already been shown, we endeavor to drink the entire river. Unfortunately, too, during that time in the year when the rain water would make the river comparatively wholesome, by diluting it with pure water, the rapid drainage brings down the filth and sewage accumulations from the river banks. So the very time we ought to get comparatively pure water, we get it very impure. You are probably aware of the fact that when the water looks the dirtiest, it is not necessarily at its worst. In this condition it is often less harmful then than when quite clear.

I therefore thoroughly agree with the speaker that the Schuylkill cannot be relied on for our future water supply; nor to my mind can any simply impounded basin be relied on for the water supply of Philadelphia. We have in any impounded basin the very conditions going on to which I have alluded in speaking of the lower Schuylkill. If you dam up a stream and let even pure water run into it, there will be discharged into the air, as vapor, pure water and comparatively impure water will be left in the reservoir. I believe it has been the experience of almost all our large cities that have tried the impounding plan that it does not give satisfaction; not only from the disagreeable cucumber odor given to the water, but from other reasons.

The Schuylkill must undoubtedly for many years to come be looked upon as the source of our city's water supply; but, looking beyond this time, can we safely, for the next three or four generations, derive our water from this river? Were this river all we could get, of course we must go to it. That settles the question. I do not, however, believe so. It has sometimes seemed to me not such a very wild or visionary scheme to go to some magnificent natural subsidence reservoir like any of our great lakes. I know the distance is very great, but so is the population along the Atlantic seaboard. If some

plan could be devised by which our large cities could share the expense, then it does not seem to me so impracticable to look to the great lakes for our water supply.

We have other waters than the Schuylkill, however, close at hand. It is indeed a very fortunate circumstance if, as Col. Ludlow has remarked, the upper sources of the Delaware will probably, from their character, never for a long time to come be improved or cultivated. If no mineral deposits that would lead to extensive mining operations be discovered in the upper basin of the Delaware, then we may perhaps rely on the Delaware for our future water supply. But even here does not the same old question still suggest itself? Will not, in the remote future, the valley of the Delaware become densely populated and thus pollute this stream?

There is one thing which to my mind seems somewhat of a danger, and that is the discharge of the Intercepting Sewer into the Schuylkill immediately below the dam. There is scarcely opportunity for the suspended solids to do anything but settle immediately in the bed of the river. I am aware that the discharge of the sewer at this point is but a temporary expedient; but I fear we are going to permit a temporary expedient to bring a great deal of trouble on Philadelphia; a trouble that may cost much to remove.

Already some of the best sections of our city discharge their sewage into the river below the height of mean tide. On the rising of the tides the water backs up the sewer and causes a dangerous leakage of sewer gas into the houses; added to this, the prevalent southwest wind brings very unpleasant odors as it is from the lower Schuylkill; so that if we add to these sources of danger, that arising from the formation of sewage deposits in the Schuylkill at this point, the danger may become very grave. It does seem to me that this is something that we ought to be very careful about—spend a little more money if necessary—and carry the discharge a little farther below the mouth of the dam.

We have only to look at the forebay of the Fairmount Water Works to see the possibility of sediment collecting to the depth of several feet, right alongside of the inlets to the water wheels. Here, despite the velocity caused by a fall of many feet to the wheels, some six or eight feet of sediment had collected. I think there is a very great danger from similar deposits of sewage from the Intercepting Sewer, and one that ought to be attended to.

Mr. Graff.—I hoped to have this matter thoroughly discussed among the audience present to-night. Many of them have studied it to some extent and have come to it with new light. We may sometimes look so long at an object (which is really true of painters and artists) that we lose its true proportions and have to leave it and come back to it again before we are able to see its full merit. I may probably be in that position; therefore, I feel that there may be parties here who might look on and discusss this matter with new light. I think there may be one thing said, and that is the point to which Col. Ludlow has referred: the fact that until the period when he was enabled by action of Councils to take up the matter there had never been suitable surveys made such as would enable the citizens of Philadelphia or the engineers employed to come to any positive conclusion in regard to the proper future supply of the city of Philadelphia. I am glad to say that these surveys have now been carried on for some length of time; not only have been carried on, but with the utmost care and with all the light and science that can be brought to the subject. Probably many of you realize how much there is to be considered. The developments of the day have taught us all very much more than we knew in former years; and the questions that attach themselves to this subject are so numerous and varied that it would be tiring you to go into them to-night. There are not only the surveys of the country; there are other objects besides that. We are only learning now how much of the rainfall can be utilized from a given area of county and how pure it will come to us when we get it. That matter is made variable by the condition of the country, particularly the wooded condition, the effect of cutting off the timber of the forests and all such matters. Col. Ludlow has shown you by demonstration that the Schuylkill river is now suffering from reduced volume produced by that cause. Therefore it behooves us all, and particularly those interested in the subject, to study thoroughly what may be the effect upon the Delaware and other streams suggested. Continued studies of these points have to be made when considering such a subject as this. They are now being considered. The geology and the surveys of the county examined have been so thoroughly gone over by Col. Ludlow that they are resorted to, and as far as they go, will be used for the geological surveys of the State; this is to show how thoroughly the surveys are being made. I agree with Col. Ludlow, that at this stage of the matter, it

would not be proper for any engineer to say positively what shall be the supply of the city in the future.

It is only feeling our way just yet That way has been felt very far, and probably very soon an opinion, perhaps a very accurate one, can be formed. I shall be willing to leave the matter in the hands of the Chief Engineer until these surveys have been completed and the whole subject thoroughly studied up. The balances that he tells you about of all the different plans investigated can then be made very important, but can hardly be gotten at until the surveys are completed. In the meanwhile, do what we may, we have to resort to the Schuylkill for our supply, because any comprehensive plan of supply is a work which will occupy much time. Even if we were to-day prepared to say that the Delaware is the proper source of future supply and the building of an aqueduct were determined upon to-morrow, the difficulty of getting from the State appropriations necessary to carry on such a work is so great that a number of years would elapse before it could be brought into use. Therefore, in the interim, we are obliged to do the very best that we can with the supply we get now. Prof. Houston has said, very properly indeed, that the Schuylkill has the disadvantage of being bottled up in Fairmount pool in the summer months, when the water is low and the outlets are only through the wheels at Fairmount and the locks, because at that time the pumping there has to stop and steam power take its place. Therefore the ability of the stream to purge itself from impurities is reduced just at the time when you want it to be the most pure. Another point comes in with that consideration, and that is, to-day we cannot store sufficient water in our reservoirs to give it the possibility of subsiding in any way. I think I am right in saying that the maximum storage in summer in the reservoirs is scarcely two days of the whole supply. Therefore, any discontinuance of pumping, you will necessarily see must reduce the reservoirs to so low a point as to make it very unsafe. The reservoirs are so small that the water may be said to simply go through them—in one side and out the other. No time can possibly be allowed for subsidence, whilst the storage capacity is so limited. As we have to continue using the Schuylkill the palliation, not an entire remedy, is the erection of larger reservoirs, a relief which I hope soon will have some attention. The subject of making an appropriation is now before the Legislature and possibly something will be done with it. The subject of the purity of the water in the Schuylkill (the impurity, I

should say), is one there can be no kind of doubt about. At times it is measurably pure, at others it is not so. There is no use of disguising the fact. As I said before, a little palliation might be made by ability to store water. The subject of any relief of the Schuylkill, I think, has been pretty well gone over by the Chief Engineer. It is a very serious point; when you come in any way to disturb the industries upon the Schuylkill valley, of course there will be more or less difficulties; such difficulties the Colonel has encountered, and has to a certain extent met. Protection may be insured by the sewer now building to carry the impurities below the point of supply. After all the matter comes down to obtaining the light necessary to form an early decision as to what shall be the future supply. I think the surveys now making will give us this light, and with the head we have conducting them, we are likely soon to come to a conclusion on that important point.

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COLORED CORONA.—Cornu notices several interesting particulars in the late phenomena of colored illuminations surrounding the sun. The reddish corona, concentric with the sun, observed by Thollon and Forel, is the simplest manifestation; it appears in perfect form only when the sun is at a great height above the horizon in the midst of a sufficiently clear sky. When the sun declines, the lower arc of the corona enlarges and becomes more intense; underneath from the horizon springs a colored band of the same tint which extends toward the corona as if attracted by it and finally surrounds it. During this change the brilliant interior space of a slightly bluish whiteness remains sensibly circular, but by an optical illusion the sun seems to be drawn toward the lower border. Towards sunset the tints gradually change first to a Naples yellow then to a brownish yellow. After sunset the corona puts on the appearance of a light smoke which gradually fades away, the colors blending with those of the setting sun. Mist or light cirrus generally effaces all these phenomena; but thick cumulus with openings of blue sky is sometimes attended with a bright copper-red, shading through various intermediate tints into the azure of the sky. The corona introduces a great perturbation in the polarization of the sky, varying the distances of Arago's, Babinet's and Brewster's neutral points from the solar or antisolar centres and is attended by four new neutral points placed in pairs nearly at the height of the solar and antisolar centres.—*Comptes Rendus*, Sept. 22, 1884. C.

THE OLDEST EUROPEAN CITIES.—The oldest city in Europe is Argos, in Greece, founded about 1850 years before the Christian era. Next in order are Athens and Thebes, in Greece; Cadiz, in Spain; Cumæ, Syracuse, Locri, Rome, Crotona, in Italy; Saguntum, in Spain; Bysantium; and lastly Marseilles, which was founded 580 B. C.—*Les Mondes*, Sept. 27, 1884.

# ISOCHROMATIC PHOTOGRAPHY.*

By Fred. E. Ives.

For the purpose of better illustrating the capabilities of my process of Isochromatic Photography, I have recently made a large number of photographs of a color-scale, which is made up of pieces of woolen cloth, dyed red, scarlet, yellow, green, blue, violet, magenta, etc. The exposures were made through color-screens, which were carefully selected by the aid of the spectroscope, in order that it might be known in each case what kind of light was transmitted.


I have not had time to make a set of lantern positives, but will show some of the negatives on the screen, and also one positive, made from prints which have been arranged for comparison.

* Read at the Stated Meeting of the Institute, Wednesday, May 19, 1885.

The first negative is an ordinary photograph of the color-scale, in which blue, violet and magenta are the only colors which photograph with considerable intensity.

The second photograph was made with an eosine-stained plate, exposed through a yellow screen. Light blue, green, yellow and light yellow-brown are the only colors which photograph well.

The third photograph is by my isochromatic process, and all of the colors come up in approximately the true proportions of their brightness.

The fourth is one of my chlorophyll plates exposed through a scarlet screen, and brings out with remarkable intensity all those colors which have usually been regarded as most non-actinic; but green and blue come out like black.

In the lantern positive, seven squares are shown from each negative, arranged for comparison. The first row is from the ordinary photograph, the second is from the eosine plate exposed through a yellow screen, the third is from the isochromatic photograph, and the fourth from the chlorophyll plate exposed through the scarlet screen. These photographs tell their own story so far as regards the capacity of the processes; but my investigations have revealed some remarkable facts, which I will now state briefly, without entering further into the details of my experiments:

1. Although collodio-bromide emulsion plates, stained with blue-myrtle chlorophyll alone are capable of photographing all colored objects in the true proportions of their brightness, they are far more sensitive to the extreme dark red of the spectrum, below the absorption band of chlorophyll, than to either the orange, yellow or green.

2. All red, orange and yellow objects reflect the dark red light to which chlorophyll plates are so sensitive, and bright yellow objects reflect as much of this light as red ones. Yellow objects photograph lighter than red ones by this process, because they reflect two kinds of light to which the plates are sensitive, while red objects reflect only the one kind.

3. The sensitiveness of the chlorophyll plates to spectrum yellow and green may be greatly increased by treating them with the tea organifier, which also nearly doubles the general sensitiveness, but without appearing to alter the effect in photographs made through a yellow screen. If a green screen is used, of a shade which does not transmit the dark red of the spectrum, the resulting photograph is

better when the tea organifier has been used, and does not then differ in any respect from one made by exposing an eosine-stained plate through the same screen.

4. The dark red of the spectrum passes freely through a solution of chlorophyll, and through ruby and orange glass, but is absorbed by common green glass, or by solutions of sulphate of copper or Prussian blue.

These facts show that plates prepared with both sensitizers, according to my original instructions, are, strictly speaking, more nearly isochromatic than those prepared with chlorophyll alone; but that in the production of photographs of colored objects they seldom offer any practical advantage, except that of reducing the exposure about one-half, at the expense of some extra labor and care in their preparation and development.

It is also evident that the safest light in which to prepare and develop chlorophyll plates is neither ruby nor orange. The light which I find most suitable for this purpose is that transmitted by a combination of two thicknesses of deep orange glass with one of green.

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SECULAR VARIATIONS OF MAGNETISM.—Duponchel discusses the normal component of æthereal undulations which produces gravitation, and the tangential component which is manifested by heat, light, electricity, etc. The tangential undulations are of two kinds: a spherical wave of rotation with maximum intensity at the equator, and a cylindrical wave of rotation with a variable grand circle base, normal to the trajectory. The combination of these two waves gives rise to an equator and poles of energy which may be deviated by perturbations in the direction and velocity of translation. Each planetary body, in addition to its own poles and equator, has a secondary system resulting from the induction of the solar equator and poles, and subject to modifications of solar movement by planetary actions. These actions are of two kinds, one in an inverse ratio to the distance, due to planetary eccentricity, and one proportional to the distance, resulting from the sun's orbit around the centre of gravity of the solar system. The first is especially sensible in the case of Mercury, which, from its proximity and its great eccentricity, produces four annual undulations, which are clearly discernible in the curves of sun spots and of terrestrial temperatures. The two actions are combined and mutually re-enforced for Jupiter, while they are nearly neutralized for Saturn. From the secular variations of magnetism which are brought about by these combined actions, Duponchel infers the existence of an unknown planet, with a period of about 467 years, which is now traversing the constellation Capricornus.—*Les Mondes*, Nov. 1, 1884. C.

# ON THE THEORY OF THE FINANCE OF LUBRICATION, AND ON THE VALUATION OF LUBRICANTS BY CONSUMERS.*

BY ROBERT H. THURSTON, Hoboken, N. J.

It is proposed by the writer, in the following paper, to consider the errors of the customary methods of finance, in their relation to the subject of lubrications, to exhibit the correct theory of such finance, as it appears to him, and, finally, to show what is the proper method of valuation of lubricants. The singular and important losses which often arise from the common system of purchase, application, and valuation of the various unguents, will be exhibited, and illustrations will be presented, both of the present and of the proposed systems.

This subject was first studied by the writer some years ago, and it was shown, in a work published at that time,† that very serious losses may follow the application of lubricants to machinery with no other guide to economy than the relation of their market-prices and their friction-reducting power and endurance, under the given conditions of use. The equations here presented were, in most cases, subsequently developed in illustration of the principles outlined in that work, and were first presented for publication in a paper read before the American Society of Civil Engineers, as a portion of a discussion at a recent date.‡ The whole subject has also been traversed in the later work of the writer on the subject of friction and machinery,§ in which a chapter is devoted to the matter of finance in this connection. The following paper is intended to give a more detailed exposition of the subject than has hitherto appeared, and to present a larger collection of facts and data than could properly be given in the later work. A large proportion of this information also was not available at the earlier dates.

The writer is under obligations to Messrs. C. J. H. Woodbury, J. C. Hoadley, and T. N. Ely, for information which they only could

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* Read at the Atlantic City Meeting of the American Society of Mechanical Engineers, May 25, 1885.

† "Friction and Lubrication." New York, 1879.

‡ "On the Real Value of Lubricants," etc., Jan. 7th, 1885; Trans. Vol. XIII, p. 476.

§ "Friction and Lost Work in Machinery and Mill-Work." New York, 1885.

satisfactorily supply, as well as to a number of other gentlemen who have kindly contributed facts and figures of great interest in this connection.

The Cause of Lost Work, in machinery, will be found, on the most casual examination, whatever the kind of mechanism, to be due, in every instance of well-designed and properly managed apparatus, to the friction of parts moving in contact and under pressure. Further examination will show that it is the almost universal custom to endeavor to reduce this waste of energy to a minimum, by the use of lubricants which are interposed between the rubbing surfaces. The inference at once follows that the unguents form a class of materials the importance of which can hardly be overestimated. The efficiency of these substances, and their value in the market, thus become matters of supreme importance, since the efficiency of the lubricant determines to what extent it is possible to reduce such losses of work and enegy, and the price determines to what extent this is commercially allowable, and the cost of such economy of work and power. There is evidently some relation of price, efficiency of unguent, and value of work saved or wasted, which will determine just what lubricant may be best used. It is evident that the relation of either two of these quantities does not indicate which is the proper lubricant, or give the real value to the consumer of that which he may select for use.

It is obvious that the real value of any friction-reducing material has no necessary or direct relation to its market price, except in so far as that price comes in to determine the financial aspect of the question which arises when it is necesary to choose which of any number of available materials is, on the whole, best for a specified case. Its real value is actually dependent, not only upon its own intrinsic properties, but also upon the value of the power which is to be saved by its application. Its value to the consumer is thus dependent upon economical conditions entirely apart from those of its production by the vender—conditions which include all which influence the total cost of the power saved or wasted, indirectly, as well as directly.

The losses due to this friction of the working parts of machinery include vastly more than the mere loss of power in overcoming that friction. They involve, often, an enormously greater amount of expense in the meeting of incidental losses, in the wear and repair of bearings and of journals, in the expenses arising from accidents traceable, more or less directly, to the frictions of working parts, and in

other less easily determined losses. Fires are sometimes caused by the use of improper lubricants, or by inefficient lubrication; costly steam engines, and other machinery, have been ruined by "break-downs" in consequence of the excessive friction and abrasion caused by the use of such unguents; and fine mechanism is often seriously injured by the change of form and the "cutting" so produced.

The common system of valuation of lubricants, and of purchase, if it can be considered a system, consists simply in a comparison of the market price of the available kinds with their friction-reducing power and their endurance, where these qualities are known. Even these essential quantities are seldom determined with any degree of accuracy, and the buyer is compelled to take what he can find, try it upon his machinery, and if it produces no perceptible ill effect, to purchase at the best rates which he can obtain, and without being able to ascertain to what extent he is the gainer or loser by changing from one kind to another. It is usually assumed that of two oils having prices proportional to their endurance, or to their friction-reducing power, the purchaser may take either with practically equally satisfactory commercial or financial results. The advisability of purchasing is considered to be settled by this comparison. No comparison is made between the costs of wasted power and the expense of purchase of lubricants, as a rule, even by the most experienced buyers. It is perfectly obvious that such a system must be absolutely wrong, as must any method which does not take into account every item of profit and loss dependent upon the use of the unguent, and which does not thus make it possible to make up a balance-sheet including all such items. The real question is not whether the difference in the price of any two oils is justified by the difference in their intrinsic qualities, but whether the profit to be made in the purchase of the one, rather than the other, is not more than compensated by the cost of the difference in power, and in running expenses, produced in the mill, or the shop, or on the railway train, by such substitution. If a dollar expended for oil may be made to show a profit of 25 per cent., in any given case of a change of lubricant, as represented on the books of the purchaser, it by no means follows that he has gained by the operation. It is very likely to be—and, indeed, is often—the fact, that a comparison of the total running expenses of the establishment will show that this apparent profit has been made by the production of an actual net loss, in cost of power and other expenses, vastly exceeding the saving in purchase-money.

To make the change advisable, it is evidently necessary that the total cost of operating the establishment must be reduced permanently, or so long as the new oil is used, by the subtitution of the latter for that formerly in use. To determine whether the change is profitable, therefore, it is necessary to ascertain just what are the items of expense affected, and to what extent the proposed change will alter their total amount. The total expense to be charged to the friction of machinery consists of the following items, as principals, and probably of minor and less easily determined expenses:

(1.) The cost of power produced, only to be wasted by that friction.

(2.) The expenses incurred in wear and tear of running parts, and in the replacement of parts destroyed, either by direct strains or by gradual wear due to such exceptional ressistances as are the effect of excessive friction.

(3.) The casual, the indirect, and often unperceived, yet none the less serious, losses throughout the system which are not included in the above.

(4.) The cost of the lubricating materials applied for the purpose of ameliorating these losses.

The first item includes a part of the expense of the prime mover, such as cost of fuel and oil used on the motor, interest on the capital invested in the machine, and in the machinery of transmission, wages paid engineer and firemen, or other attendants, insurance and taxes upon that part of the plant, including so much of the building as is properly chargeable to the motive-power department. The second item includes costs of repair, refitting or replacement of journals and of bearings, the repair of break-downs caused by excessive friction, or by hot bearings seizing the journals, and, often, the cost of throwing out the whole machine and introducing a new one to take its place. The conditions determining the life of the machine, in fact, are what are included under this head. The third item includes the exceptional damages resulting from friction of excessive amount, and which may be more likely to occur with one oil than with another. Its amount can never be calculated with any great degree of exactness. A hot journal may cause the delay of a train, and consequently a collision involving loss of life and destruction of property; a chronometer suddenly changes its rate, in consequence of the abrasion of some dry spot on its arbors, and causes the wreck of a steamship freighted with human beings and valuable cargo; the quality of the fabrics made in a cotton

mill making fine work, because of defective lubrication, is altered by the breaking of threads, by the imperfect action of looms, or by the lubricant spotting the cloth. Such losses are experienced very frequently in manufacturing, and in every mechanical operation, and are very seldom exactly calculable. The fourth and last item is usually, it is probable, the least important of all. It is, however, one which appears most prominently, and which is, therefore, most certain to appeal directly to the mind of the interested proprietor, and to the buyer of the oil. It will be seen, later, that this is so small an item, in many instances, that it becomes absolutely unimportant, as influencing the choice of lubricant.

The differences in the magnitudes of the losses comprehended in the first three classes of expenses, as above, are enormous; those occuring in the costs of oils and greases, as effecting those expenses become utterly insignificant in comparison.

Such are the several classes of costs, the variation of all of which must be considered in any system of valuation of lubricants, and in any systematic theory of the finance of the subject. It is obvious that a gain is effected, on the whole, only when the reduction of total cost, as above measured, is reduced; and it becomes economical to buy a cheaper lubricant only when its use leads to a decrease of expense in its purchase which is not compensated by an increase in the sum of the first three items above enumerated. Where all four items are diminished, the advisability of the change is indisputable; but when, as is, probably, usually the fact, decrease in cost of lubricant implies increase of friction and loss of power, a careful balance must be struck.

Before the real value of any lubricant to the consumer can be determined, therefore, and whether any proposed change is desirable on the score of economy, it becomes necessary to ascertain the total expense chargeable to friction, in a manner already indicated, and to compare the difference of cost of unguents with the difference in costs of other items of expense produced by change of lubricant in the manner intended. In making this comparison it is first necessary to determine in what terms these expenses may be best expressed, and in what magnitude they enter the equations representing the problem.

(1.) The cost of power wasted may be expressed in the usually adopted terms, the cost in dollars per horse-power and per hour, or per year; or it may be given in foot-pounds of work, irrespective of time. The first of these methods of valuation is the more common.

This quantity varies greatly in different localities and in different establishments; its average and fair value for ordinary cases will be given be given presently.

(2.) The cost of wear and tear, and of depreciation, is an even more variable quantity than that of power. It cannot be stated definitely and generally; but it may usually be very fairly measured for any given case. An allowance is customarily made based upon the value of all machinery subject to this kind of depreciation. It will always be permissible to take this expenditure, in any establishment considered, as proportional to the power employed, and to include it thus in the first item. It will be so included in the treatment here adopted. It sometimes happens that a decrease of the total power wasted by friction is accompanied by an increase in the amount of wear: in such cases the oil producing this remarkable effect, which is usually a mineral oil, without admixture, having too little body for its work, should be rejected without further investigation.

(3.) The third item, the casual and irregular losses, should, where possible, be made a constant and regular item of charge by securing insurance against all such kinds of loss. Where this cannot be done, the proprietor should insure himself by accumulating a fund to meet this expense, assuming a rate of accumulation which experience may determine to be safe, for a series of years. This item then becomes chargeable as so much insurance, and can be introduced, with other insurances, in the first of the above divisions.

All three of the charges above described may evidently be thus brought to one method of charging, and may be entered upon the account as so much per horse-power and per hour, or per year, or per foot-pound of work if preferred.

(4.) The fourth and last item, the cost of lubricant, is measured by the charge per gallon, and by the number of gallons used per hour, or per annum, or for the specified work. This is, in every case, ascertainable by observation, or trial, either in the establishment in which it may be used, or upon the testing-machine, under precisely the conditions, if attainable, as to pressure, speed, temperature, and condition of bearing surfaces, of its application, in the shop, the mill, or on the axle of a railway train.

Having thus reduced all expenses arising from the existence of friction to one measure, the dollar, and the cost of the lubricant being expressed in similar terms, it becomes easy to solve the most vital of

the economical problems arising in this connection. These two items, thus determined, being ascertained in magnitude, for each kind of lubricant, a comparison of the totals settles the question of profit or loss. In every case, the exact value of the items being ascertained, the conclusion becomes evident and certain. It is further evident that the uncertainty arising, in any attempt to make application of these principles, comes, in every case, not from inexactness of the principles, but from the difficulty, should any exist, of determining the exact values and precise conditions.

The algebraic theory of this case is constructed very easily, and in a very simple manner, as follows:

If, in any case, $U$ be taken as the measure of the power wasted, or of the work lost per hour or per annum, and if $k'$ be its total cost, as above, for the unit of time, and if $q$ be the quantity of the lubricant used in the same time and $k$ is its cost, including its application to the journals, the total expense chargeable to friction, being called $K$, must be measured by

$$K = kq + k'U \tag{1}$$

But the work done is equal to the product of a constant, $a$, dependent upon the units employed, the value of the coefficient of friction, $f$, the total load, $P$, and the space passed over by the rubbing surfaces, $S$, which last is also equal to the product of the velocity of rubbing, $V$, and the time, $t$, taken as the unit of comparison. Then

$$U = afPS = afPVt \tag{2}$$

and the cost, $K$, thus becomes

$$K = kq + k'afPS \tag{3}$$

or,

$$K = kq + bf \tag{4}$$

in which $b$ is a constant, in any given case, and equal to

$$b = ak'PS, \tag{5}$$

and the equation, as thus simplified, may be applied to all cases.

The value of $f$ is to be ascertained by experiment, under the exact conditions of use, and this being determined, the total cost becomes calculable, and a satisfactory comparison may be made. That lubricant is best which, all things thus considered, gives the lowest value of $K$, and where wear of serious amount occurs, as may happen when using oils badly adapted to the pressure and speed, the cost of such

additional wear must be put in as an additional charge. With properly chosen oils, in regard to which, only, any doubt can arise, in the endeavor to make a selection, this may be probably usually neglected.

The value of the oil, in terms of the total cost and of cost of wasted power, is

$$k = \frac{K - bf}{q}, \tag{6}$$

which equation shows that the value is the greater as the quantity demanded is less, and that it also increases when the coefficient of friction decreases. These equations, also, show that the total cost is very nearly proportional to the coefficient of friction when, as is the usual case, the cost of lubrication is small in comparison with that of the power wasted. The value of the lubricant is then very nearly proportional to the reciprocal of the coefficient of friction, and has no necessary, or direct, relation to the market price. It will be seen, later, that this conclusion is correct, and that the price of an oil, and even the quantity consumed, are matters of little importance, as a rule, in comparison with the amount of gain or loss of power by variation ot friction of moving parts due to change of unguent.

Two oils being compared, the costs of wastes are, respectively,

$$K_1 = k_1 q_1 + bf_1; \; K_2 = k_2 q_2 + bf_2, \tag{7}$$

and the saving effected by the use of the better lubricant is

$$K_1 - K_2 = k_1 q_1 - k_2 q_2 + b(f_1 - f_2). \tag{8}$$

If the saving in value of power lost is just equal to the difference in cost of lubrication, it is evident that the change will not affect the total cost, and it is a matter of indifference whether it is made or not. That is to say, if $b(f_2 - f_1) = k_1 q_1 - k_2 q_2$, we shall have $K_1 = K_2$ and profit and loss are equal. When $b(f_2 - f_1) > k_1 q_1 - k_2 q_2$, the result is evidently a gain; and when the first member of the inequality is less than the second, a loss is effected. Thus we have a criterion of the advisability of changing the lubricant in the equations:

$$K_1 = K_2; \; k_2 q_2 - k_1 q_1 = b(f_1 - f_2) \tag{9}$$

$$k_2 = \frac{k_1 q_1 - b(f_2 - f_1)}{q_2}. \tag{10}$$

If two oils are compared, therefore, it is seen that, the first having the price, $k_1$, giving the coefficient, $f_1$, when used in the quantity, $q_1$, the second may be profitably used in the quantity, $q_2$, if giving the

coefficient, $f_2$, only when it can be purchased below the price $k_2$ of equation (10), the two prices being considered as including the cost of application to the bearing and of removal. Should the oils compared have so little body that wear takes place to any appreciable extent, the cost of the wear is to be added to the cost of power, in each case.

If, in any case, as often happens, the quantity used is practically the same, whichever oil is used, $q_1 = q_2$ and the criterion becomes:

$$k_2 - k_1 = \frac{b}{q_2}(f_1 - f_2); \tag{11}$$

$$k_2 = k_1 - \frac{b}{q_2}(f_2 - f_1) \tag{12}$$

The allowable purchasing price is below the value thus obtained.

Where the same oil is used, but may be applied in greater or less quantity, we may obtain, similarly, a criterion for the quantity to be profitably used. It is evident that the advantage of increasing the quantity is to be found in the reduction of the cost of power and incidental losses. If, in any two cases, we get

$$k(q_2 - q_1) = b(f_1 - f_2) \tag{13}$$

the gain just balances the loss, and the criterion becomes

$$q_2 = q_1 + \frac{b}{k}(f_1 - f_2) \tag{14}$$

and, assuming it to be found, as is usual, that a decrease of power follows increase of freedom of supply of lubricant beyond the amount customarily given, the limit is reached at the above amount. This statement must, however, be qualified by the reminder that it is often possible to supply oil as freely as may be desired, without important loss, by the use of a good system of collection and renewal, with occasional purification. The comparison then lies as in the first cases, the costs including those of purification and replacement. As the friction of lubricated surfaces is sometimes affected to a very great extent by variation in the rate of supply, especially at high speeds of rubbing, this case becomes important. The lower the cost of the oil, in any case, and the higher the cost of power, the more freely should the unguent be supplied to the bearing.

When the relative durability and the coefficients of friction of oils proposed in any case, are known by direct experiments made under the precise conditions of intended use, it is equally easy to determine,

wear being neglected, what are their relative money values. If an oil already in use be taken as the standard, and if an oil to be compared with it is found to have $e$ times the endurance of that standard, the quantity used should be $q_2 = \frac{q_1}{e}$. If the second oil have a coefficient of friction $h$ times as great as the first, the work of friction will be correspondingly reduced or increased, and the cost of that work will be $bhf_1 = bf_2$. The total costs will then become

$$K_1 = k_1 q_1 + bf_1 \tag{15}$$

$$K_2 = k_2 q_2 + bhf_1 \tag{16}$$

and the criterion is obtained, as before, by making these expressions equal, whence

$$K_1 = K_2 ; \; k_2 = \frac{[k_1 q_1 + bf(1-h)]e}{q_1} = ek_1 + bef_1 \frac{1-h}{q_1}. \tag{17}$$

Any cost, on the journal, less than this value of $k_2$ is profitable; any higher cost will produce a loss. At this cost, the user will neither gain nor lose by the change of lubricant.

It is obvious that the value of $b$ may be expressed in any convenient units of cost quite as well as in those above taken. It is usual to measure costs on railways by amounts per train-mile, as, for example, pounds per train-mile, in measuring expenditures of fuel, miles run per quart, or per gallon, in rating expenditures of oil. As has been seen, these are but a part of the total expense; but it may sometimes be convenient to obtain an approximate estimate of the relative values of lubricants, on the assumption that wear and other costs may be neglected, and the value of $b$ is then to be expressed in the money value of fuel used per train-mile; which cost will evidently be proportional to $f$. The relative costs will be proportional to the values of $h$.

In railway practice, it is often found that the cost of wear is a very serious item, but probably only when using an oil which is unfitted for use as a lubricant, and which should never be used at all, as some of the black mineral oils. Could the lubrication be as effectively carried on as in other cases, and could the dust be perfectly excluded, the loss from this cause would become insignificant. Assuming this to be the case, we may write the equation for this case,

$$K = kq + df \tag{18}$$

in which $df$ is the total cost of power per train-mile.

The criterion is found as before, substituting $d$ for $b$, in the several equations already derived,

$$k_2 = \frac{k_1 q_1 - d (f_2 - f_1)}{q_2} \tag{19}$$

As, in all cases, the cost of power wasted is a function of the quantity $q$, if the law of variation can be ascertained and expressed algebraically, the most economical rate of supply can be ascertained in making $\frac{dK}{dq} = 0$, for a minimum. Similarly, the best value of $k$ may be determined, for the case in which the same quantity is always used, by making $\frac{dK}{dk} = 0$.*

The numerical value of the items which have been found to constitute the costs of lubrication and wasted power must be determined before application can be made of the theory of finance just developed. Among these items, the price of oil, as has been remarked, is the least important; but it is that which is most prominent, as a rule, in the view of the buyer, as well as of the seller. These prices are continually varying, and it is impossible to find values for $k$ which may be taken at all times probably correct, or as being always fair. The real value of the figure to be assumed is, as already stated, the cost of the lubricant on the journal, and includes the cost of application, as well as the market price. The figures given below will be taken here as fair values of the unguents named, as now sold in the market. In each case, the oil is assumed to be a goed representative of its grade, such as may reasonably be expected to be obtainable in the market by any skillful and experienced buyer who may choose to secure it.

*Prices of Lubricants.*

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|---|---|---|---|
| Sperm oil, per gallon | $1 10 | Heaviest mineral oil, per gallon | $0 75 |
| Neats-foot, " | 1 00 | Medium machinery oil | 50 |
| Tallow oil, " | 70 | Light lubricating oil | 25 |
| Lard oil, " | 70 | Crude well oils | 20 |
| Greases, per lb | 25 | Kerosene (unrefined) | 10 |

These figures can only be taken as illustrative. The prices obtained in the market for the machinery oils vary enormously, and without any fixed relation to their values. One maker has no spindle oil at a lower price than $0.40; while others make what they call spindle oils

* *Encyclopedia Britannica.* Art. Lubricant.

at one-half that price. Other oils and the greases, animal and vegetable, are subject to similar, but usually smaller variations of price. In one case, the maker obtains less than 15 cents per gallon for a machinery oil; while the vender of a trade-marked oil uses the same grade, buying at that price and selling at a profit of several hundred per cent.

The quantities of oil used for the various purposes of lubrication differ quite as much, where distributed by different hands, as do the prices. It may probably be estimated that at least one-half of all the power expended in the operation of the average manufacturing establishment is applied to the work of overcoming the friction of lubricated surfaces. The coefficient of friction will average a high or low figure according to the kind of machinery. The heavier the latter, the lower the friction coefficient. Light machinery gives a high value of friction, which is therefore very great on the spindles, and on the machinery generally of the textile manufactures, lower on the heavy machines of the iron-working trades, and very low, comparatively, on the axles of railway engines and cars. The range is probably from twenty down to one per cent., or even less. It will be here taken as averaging, in good practice, ten per cent. in mills, five per cent. on heavy machinery, and one per cent. on railways. The oil must evidently be selected with a view to its use, the heavier pressures and lower coefficients being necessarily obtained with heavy lubricants—oils or greases—and the lower pressures and higher coefficients being given where the lightest possible oils are properly and customarily employed, with more copious supply.

(To be Continued.)

Siliceous Bronze.—Copper, which is desirable on account of its great conducting power for electricity, cannot be employed on long circuits, on account of its great ductility. Henri Vivarez finds in siliceous bronze a conductibility comparable to that of copper, and a mechanical resistance greater than that of iron. The silicium may be introduced in various proportions, the mechanical resistance varying inversely as the conductibility, so that different qualities may be obtained, adapted to the different services which are required; thus in telegraphy, wires of galvanized iron which weigh 155 kilogrammes per kilometre, can be replaced by wires of siliceous bronze which weigh only 28 kilogrammes; in telephony iron wire of 25 kilogrammes can be replaced by wires of siliceous bronze which weigh only 8·45 kilogrammes.—*Les Mondes*, Jan. 12, 1884. C.

# GLIMPSES OF THE INTERNATIONAL ELECTRICAL EXHIBITION.

By Professor Edwin J. Houston.

## No. 8.—Reis's Invention of the Articulating Telephone.

It not unfrequently happens in the history of science that some particular discovery or invention is made so far in advance of its time, as to fail to receive general public recognition. This is especially the case when the discovery or invention is of such a nature as to aim at a revolution of old ideas or methods. Deeply rooted ideas, prejudices, or habits are not easily changed, and unless the discoverer or inventor has unusual good fortune the new truth he proclaims to the world may fail of recognition. This, indeed, must be so until other minds are able to contemplate the discovery or invention from the same mental stand-point as its author.

The speaking, or articulating telephone, affords a remarkable illustration of a great invention born out of its time. When its inventor, Johann Philipp Reis, of Gelnhausen, Germany, as early as 1860–1861, produced the instrument that he named the "telephone," and claimed for it the ability to transmit musical sounds and articulate speech, the claims were received with incredulity. Even Prof. Poggendorff, editor of the *Annalen,* who might have been expected to have been better informed, went so far as to refuse to publish a written description of the instrument which Reis sent him as early as 1862. The electrical transmission of articulate speech was regarded by Poggendorff as a scientific impossibility, and it was not until the year 1864, when Reis gave a descriptive lecture of his instruments at Giessen, and exhibited the apparatus to some of the most distinguished scientific men in Germany, that Poggendorff, at last able to appreciate the labors of Reis, requested the latter to prepare a description of the same for publication in the *Annalen.* This request Reis very properly refused. Even the Physical Society of Frankfort, before whom Reis gave the first public lecture on the telephone, although it extended to the inventor the recognition of election as a member, was apparently unable to properly appreciate the importance of the discovery, and so took no further notice of the same.

Reis made various improvements on his instruments and showed

them in actual operation as transmitters and receivers of articulate speech to many parties of well-known scientific ability in Germany, some of whom are still living. His failure to impress the general public with the importance of an invention that he himself clearly saw, doubtless hastened his untimely death, which occurred at Friedrichsdorf, January 14, 1874.

Various improvements and modifications of the original apparatus of Reis were made by different inventors, but they too failed to receive general public recognition, and at the time of the announcement of Bell's telephone, especially at the time of its exhibition at the Centennial Exhibition in Philadelphia, in 1876, the researches and inventions of Reis were almost forgotten.

The times were more propitious for Bell, and his instruments were very favorably received by the scientific men who saw them at the exhibition. The fortunate circumstance of an exhibition which attracted to it the leading scientific minds of the world, gave the trials of the Bell instruments advantages that were denied to those of Reis. The enthusiasm attending this exhibition was wide spread, and Bell was hailed by many as the inventor and discoverer of a new art, while poor Reis, the true inventor and discoverer, was almost forgotten. Indeed, even at the present time, the most extravagant claims are made on Bell's behalf as the inventor of the articulating telephone, claims that are actually construed to give to Bell priority of invention in the employment of electricity for the transmission of articulate speech. A careful consideration of the claims of Reis as the first, true, and original inventor and discoverer of the articulating telephone, clearly prove the remarkable advance he had made in the art of telephony, so that at the present time the majority of scientific men discredit the claims of Bell as the discoverer of a new art, and recognize Reis as the first and true inventor, while Bell is awarded the credit of adding certain valuable improvements to the original inventions of Reis.

The public enthusiasm that attended the somewhat extravagant newspaper descriptions of Bell's first Centennial experiments has long since died away, and a careful and unbiassed examination of all the printed records of the original Reis telephone, both by the inventor himself, or by his contemporaries, leaves but little, if indeed any honest doubts, but that Reis's original instruments were intended by their inventor not only for the transmission of musical sounds, but also for the transmission of articulate speech. Reis's statements as to the pur-

pose of his invention are of the most unequivocal character, as we shall hereafter show. We find him discussing in a clear and logical manner the physical conditions requisite for the electrical transmission of speech. At first he is almost disheartened at the difficulties that must attend the construction of a single instrument that should be able to reproduce all the actions of the various organs concerned in human speech.

Starting from what had been already accomplished, as in the talking machine of Faber, he endeavored to conceive a simple mechanism that would replace the organs of the mouth and throat that are concerned in the production of articulate speech. He soon convinced himself of the futility of invention in this direction and took a step that marks a master mind. He abandoned the effort to reproduce the effects produced by the vocal organs and gave to himself the problem of how best to imitate the action of the human ear. He philosophically discusses the action of this organ in the reception of sounds, and sets about producing an instrument that can simulate such action. The outgrowth of such researches was the telephone, which, as Reis left it, contains all the essential features of the present articulating telephones in general use to-day in so many different portions of the world.

It is a curious fact, as has been pointed out by Prof. S. P. Thompson, in his book on the Telephone, that the ground gone over by Reis and Bell in the description of their several inventions is substantially the same. This, indeed, must necessarily be the case, since each was describing, in a scientific spirit, the principles involved in the production and propagation of sounds. It is, therefore, not surprising that a remarkable correspondence exists not only in the mode of treatment and language employed, but even in the graphic representations of the curves corresponding to various sounds.

Reis, however, did not content himself with the mere assertion of his ability to make his telephone transmit and reproduce intelligible articulate speech, but he actually accomplished it. Evidence of the most undoubted character exists, showing that both he and others talked through his instruments, and received communications through the same. Some of these witnesses are still alive, and rank among the most distinguished scientific men of Germany. Indeed, so well was the fact that speech had been transmitted by Reis known in Germany, that many firmly believed, on hearing of the commercial success of the Bell telephone in America, that the name referred to a particular form of Reis's telephone.

The Reis telephones as constructed by him will transmit intelligible articulate speech to-day, as can be testified by numerous able scientific men in America and Europe. The transmitter, as originally devised and constructed by Reis, is substantially the same as that employed in the commercial systems of telephony now in use.

Notwithstanding the following facts, the truth of which we believe has never successfully been controverted, viz.:

1st. That Reis expressly claimed that he was endeavoring to make an instrument that would transmit and reproduce articulate speech.

2d. That he did actually produce such an instrument and talked or listened through it, and permitted credible and trustworthy witnesses to so talk or listen through it; and

3d. That instruments constructed strictly in accordance with the instructions and descriptions of Reis will still talk, it is gravely asserted by some that the instrument invented by Reis was not a telephone at all; but a mere toy, intended, not for the transmission and reproduction of articulate speech, but merely for the transmission of musical tones. To deny that to be an articulating telephone that was claimed by its inventor to be constructed as such, that unquestionably operated as such, and that is still capable of operating as such, is, to say the least, open to grave suspicions either of want of fairness, or of an actual ignorance of the real facts of the case, that appear to be almost incredible.

It is not of course to be claimed for the original Reis instrument that it is as efficient in operation as the various instruments now in actual commercial use. But it is true that the instruments of to-day owe their superiority not so much to any new principle of construction or operation that has been introduced into them, but rather to their use of a metallic diaphragm in the place of the membranous one that was liable to variations in its tension by dampness, or to a better proportioning of parts, or of the means employed to readily adjust the same. Although this is freely admitted, yet the instrument left by Reis was far ahead of the apparatus figured and described by Bell in his application of February 14, 1876, since the former will talk, while the latter can scarcely be said to do so.

Of course we are not unmindful, in drawing these comparisons between the apparatus of Reis and Bell, that the latter, claims as the essential feature of his invention the use of what he styles the undu-

latory electrical current, without which, in his opinion, the transmission of articulate speech is an impossibility. He calls especial attention to the phraseology employed by Reis in describing his invention, when he speaks of the makes and breaks effected by the transmitting apparatus in the circuit, and claims that such apparatus could not transmit articulate speech. The argument concisely is as follows, viz.: The undulatory current is necessary for the transmission of articulate speech. Reis did not employ the undulatory current; therefore, Reis did not (could not) transmit articulate speech, (and this apparently without any serious effort to ascertain whether in point of fact Reis actually did transmit speech).

Granting the first premise here merely for the sake of argument, we reply as follows, viz., the Reis apparatus did and will transmit articulate speech, therefore Reis and not Bell is the true inventor of the undulatory current as applied to telephony.

This conclusion is so inevitable that it will readily be understood that the advocates of Bell are unwilling to admit the possibility of Reis ever having been able to speak through his apparatus, since such an admission is equivalent to an acknowledgment of the want of novelty of Bell's undulatory electrical current.

It is admitted, as must indeed be done, that the Reis apparatus will talk now, provided such skill in adjusting the same be brought to bear on it as has been acquired in the light of Bell's invention. To this we would answer that this is exactly the skill which we must admit was possessed by Reis, and which he acquired by reason of his extended experiments. Such a conclusion is inevitable, since nothing is absolutely necessary in the adjustment of the Reis apparatus that was not provided for in the same, nor is any addition to the same required. If, therefore, an expert of to-day can make the Reis apparatus talk, the presumption is manifest that Reis actually did what he and others claim that he did, namely, transmit speech through his apparatus by means of electrical currents whose intensity was varied by the action of the human voice on the transmitting apparatus.

There is no doubt that the written descriptions of Reis or of his contemporaries, concerning his apparatus, speak of the same as operating in consequence of what he terms makes and breaks in the circuit of the transmitting apparatus. In all forms of his apparatus he shows loose contacts that are caused by the vibrations of the membrane of the transmitting apparatus to vary the resistance of the circuit by

what Reis called the making and breaking of the same. This point in the description of the Reis apparatus is seized by the champions of Bell as a flaw, fatal to the claims of Reis as the true inventor of the articulating telephone. They apparently have accepted it as a "forlorn hope," and are perhaps to be congratulated for having made the most of it, having rung the changes on it and juggled with it until it seems to have acquired an importance in their eyes that it does not appear to us to possess. They claim that the operation of the Reis transmitter must necessarily be to produce abrupt makes and breaks in the continuity of the circuit connecting the transmitting and receiving instruments, and that, of course, such makes and breaks are inconsistent with the electrical transmission of articulate speech.

To the above argument, which in reality covers the only point in discussion between Reis and Bell, we submit:

1st. That even a casual reading of the descriptions of the Reis apparatus clearly shows that the inventor did not intend the same construction to be placed on the words describing the action of the voice on the contacts through the movements of the diaphragm, as the champions of Bell claim that he did. That is, that Reis did not construct his apparatus to obtain abrupt makes and breaks.

2d. That it can by no means be regarded as conclusively proved that the transmission of articulate speech necessitates the production by the transmitting apparatus of the undulatory electrical currents in the manner described by Bell.

That Reis did not contemplate the production of abrupt makes and breaks in the circuit may be clearly seen from his own description of his apparatus, which shows that he had fully grasped the necessity for his transmitting apparatus to impart such variations to the electric current as to reproduce in the receiving apparatus "vibrations whose curves shall be the same as those of any given tone or combinations of tones," since thus only, as he remarks, can we "receive the same impression as that tone or combination of tones would have produced on us."

Before, however, entering at length into a full discussion of the points above referred to, let us first see the actual character of the apparatus as Reis produced them.

The earliest transmitting apparatus made by Reis was that modeled after the human ear. In Fig. 1, which with Figs. 2, 4, 10 and 11, is

taken from S. P. Thompson's work on the Telephone, is shown various views of the transmitter, which was roughly carved in oak.

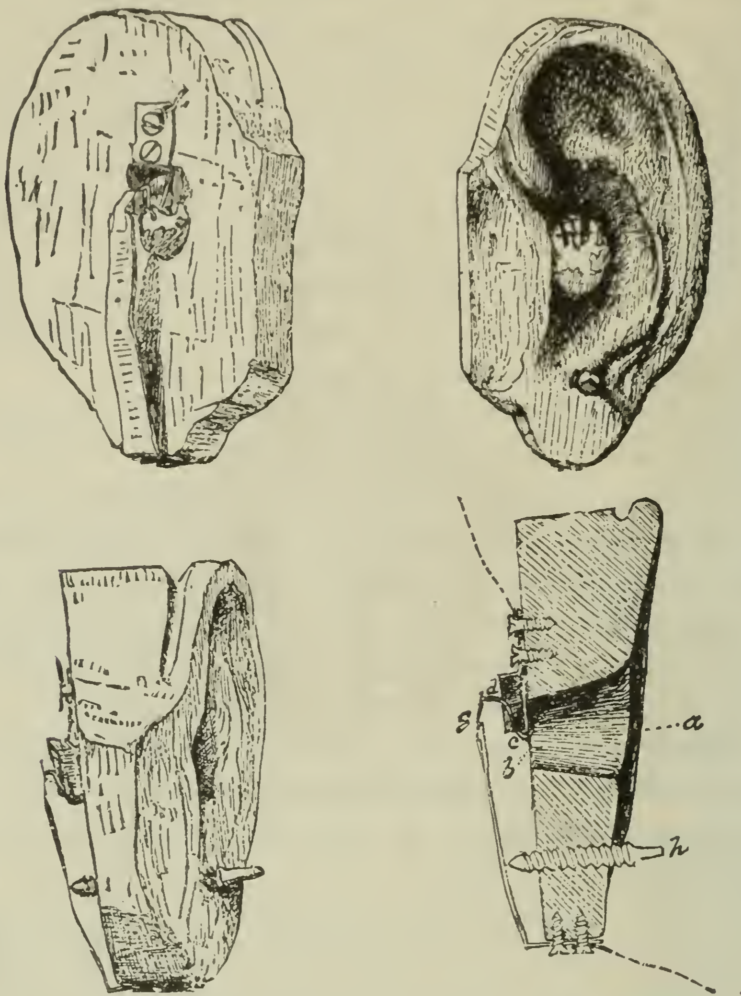



FIG. 1.—Reis Transmitter.—Human Ear Model.

An examination of this apparatus shows that it followed closely the arrangement of the human ear. For example, the cavity *a*, was closed at its further end by the membrane *b*, which took the place of the tympanic membrane. The chain of bones that connects the tympanum with the inner ear, was, in Reis's ear-model, represented by the bent lever *c d*, made of platinum wire. This lever, which was pivoted on a suitably supported horizontal axis, had its end *c*, securely fixed to the centre of the diaphragm *b*, by means of sealing wax, and was so arranged as to be able to follow all its motions. The pivot or axis, was placed near the centre of the lever and was supported in the manner shown in detail in Fig. 2.

The end *d*, of the bent lever rested with a loose contact against a spring *g*, near its upper end. This spring, whose length was about one inch, was furnished at its upper end with a slender spring strip of platinum foil. The adjusting screw *h*, was provided for the regulation of the degree of pressure between the end of the lever *d*, and its opposed surface of platinum foil at *g*.

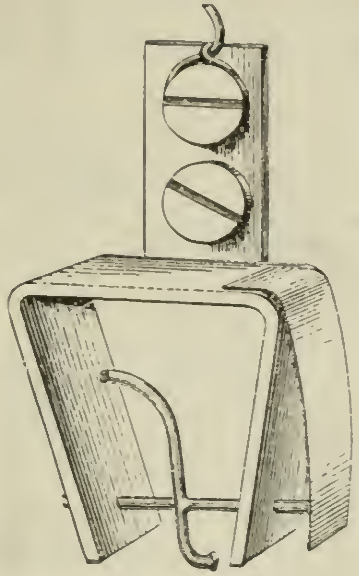


FIG. 2.—Details of Transmitting Lever.

The apparatus above described, was provided, as has been seen, with two loose contact points of metal, that were introduced as a variable resistance in the electrical circuit that connected the transmitting and receiving apparatus. When the voice of a speaker, talking into *a*, caused the membrane *b*, to be set into vibrations, the bent lever, carried the vibrations and transferred them from the membrane to the loose contacts between *g*, and *d*, thus introducing into the circuit variations in its resistance corresponding to the movements of the membrane or diaphragm *b*.

In Fig. 3 is shown another form of transmitting apparatus devised by Reis, and which is known as the bored-block transmitter.

Between the form shown in the human ear model and that shown in Fig. 3, there were several transitional forms, some of which are still persued in the physical cabinet of the Garnier Institute. These instruments were modifications of the human ear model. The details of the means they employed for varying the resistance at the loose contacts do not appear to have been preserved.

The bored-block model, shown in Fig. 3, was among the most important of articulating telephone transmitters constructed by Reis. We prefer therefore to give verbatim Reis's description of the same, together with a few prefatory remarks. We quote from a translation from Prof. S. P. Thompson's work, of an article entitled "On Telephony by the Galvanic Current, by Philipp Reis." This article appeared in the "Jahresbericht" (Annual Report) of the Physical Society of Frankfort-am-Main, for 1860 and 1861. Fig. 3 is taken from this article.

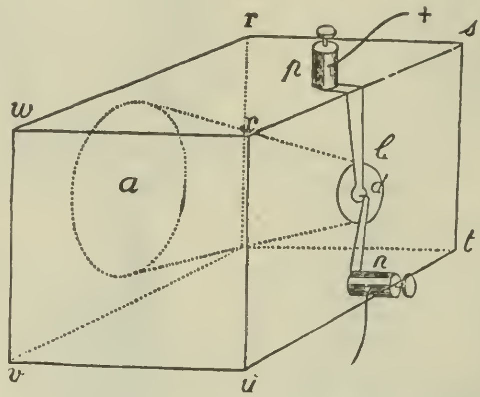



FIG. 3.—Reis's Bored-Block Transmitter.

After alluding to his early fondness for experimental physics, and to his belief, nine years previous to the date of the above article of the possibility of transmitting tones by the galvanic current, he spoke of having but really begun the problem, when discarding the idea of producing the tones by mechanism similar to the vocal organs, he made the great step of endeavoring to produce them by means of apparatus resembling the auditory organs. He then discusses the nature of sounds or tones, and the action of the ear in carrying the same to the auditory nerve. He points out very clearly that what the auditory nerve perceives is the action of a force, which force may be represented graphically according to its direction and magnitude by a curve. He discusses the forms such curves would have when produced by simple tones, and by complex tones, and then speaks as follows, viz.:

"It follows from the preceding that:

(1.) Every tone and every combination of tones evolves in our ear, if it enters it, vibrations of the drum-skin, the motions of which may be represented by a curve.

(2.) The motions of these vibrations evoke in us the perception

(sensation) of the tone; and every change in the motion must change the sensation.

As soon, therefore, as it shall be possible at any place and in any prescribed manner, to set up vibrations whose curves are like those of any given tone or combination of tones, we shall receive the same impression as that tone or combination of tones would have produced upon us.

Taking my stand on the preceding principles, I have succeeded in constructing an apparatus by means of which I am in a position to reproduce the tones of divers instruments, yes, and even to a certain degree the human voice. It is very simple, and can be clearly explained in the sequel, by the aid of the figure. (See Fig. 3.)

In a cube of wood, *r, s, t, u, v, w, x*, there is a conical hole, *a*, closed at one side by the membrane, *b* (made of the lesser intestine of the pig), upon the middle of which a little strip of platinum is cemented as a conductor of the current [or electrode]. This is united with the binding screw, *p*. From the binding screw, *n*, there passes likewise a thin strip of metal over the middle of the membrane, and terminates here in a little platinum wire which stands at right angles to the length and breadth of the strip."

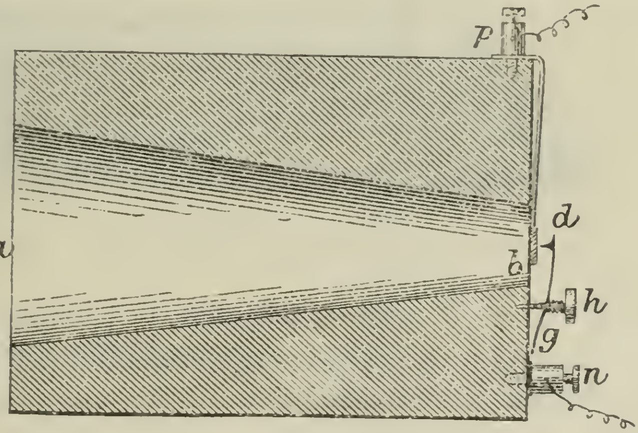



FIG. 4.—The Bored-Block Transmitter (later form).

In the form of transmitter shown in Fig. 3, no means are provided for the regulation of the pressure between the contact points, *b*, and *d*. In a transmitter of this form used by Reis, and afterwards given to Prof. Böttger, and now in the possession of Dr. Stein, of Frankfort, to whom it was given by Prof. Böttger, the details of construction are identical, with, however, this difference, that such regulating device is there provided. This later form is shown in Fig. 4. The regulating

screw referred to is shown at *h*. Since such a device was placed by Reis in his human ear transmitter, it is not unreasonable to suppose that it was placed in the bored-block transmitter by Reis himself.

The presence of these screws for regulating the degree of contact between the loose contacts that are moved by the diaphragm is not without its significance in the true explanation of the manner in which Reis designed his apparatus to operate, as we shall hereafter explain.

The next form of transmitter is shown in Fig. 5. There appears to have been several unimportant modifications between this transmitter and that shown in Fig. 3.

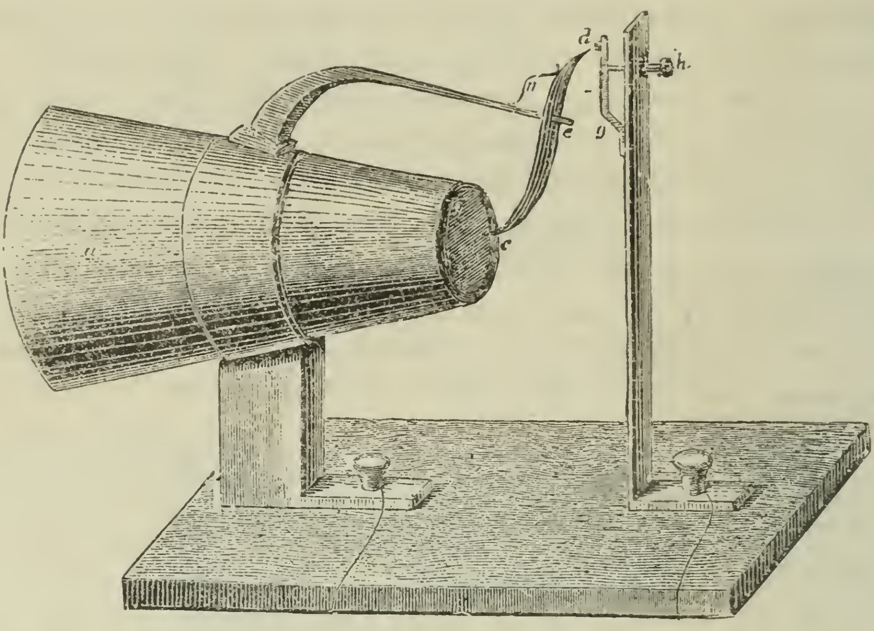



Fig. 5.—The Reis-Legat Transmitter.

This transmitter has been so named after Von Legat, Royal Prussian Telegraph Inspector at Cassel, who prepared a description of the same for the "Journal of the German-Austrian Telegraph Association in 1862." Some questions have been raised whether this form of apparatus was really invented by Reis, since no original apparatus answering this description has been found. The apparatus, however, does not differ substantially from that employed by Reis during his lecture before the Freies Deutsches Hochstift, at Frankfort, so that we may safely ascribe the apparatus to Reis.

The description by Legat of the transmitter is quite minute. We prefer to give it as taken from a translation of the article before alluded to.

"The tone transmitter, Fig. 4, *A*" (see Fig. 5 in the article) "consists of a conical tube, *a*, *b*, about 15 centimeters in length, having a front opening of about 10 centimetres, and a rear opening of about 4 centimeters.

"It appears by practical experiments that neither the material of the tube, nor any increase in its length, influenced the accuracy of the action of the apparatus. An enlargement of the diameter of the tube impairs the working of the apparatus, and it is desirable that the inner surface of the tube be as smooth as possible. The smaller or rear end of the tube is closed by a collodian membrane, *o*, and upon the centre of the circular surface of this membrane rests one end, *c*, of the lever, *c*, *d*, the supporting point, *e*, of which is sustained by a bracket, and is kept in electrical connection with the metallic conductor. The proper lengths of the respective arms, *c*, *e*, and *e*, *d*, of this lever are regulated by the laws of the lever. It is advisable to make the arm, *c*, *e*, longer than the arm, *c*, *d*, in order that the least motion at *c*, may operate with greatest effect at *d*. It is also desirable that the lever itself may be made as light as possible, that it may follow the movements of the membrane. Any inaccuracy in the operation of the lever, *c*, *d*, in this respect will produce false tones at the receiving station. When in a state of rest the contact at *d*, *g*, is closed, and a delicate spring, *u*, maintains the lever in this position." . . . . .

"Upon the standard, *f*, is arranged a spring, *g*, with a central point corresponding to the central point, *d*, of the lever, *c*, *d*: the position of *g*, is regulated by the screw, *h*." . . . . . . . . . . . . . .

The operation of the apparatus described is as follows:

"When at rest the galvanic circuit is closed. When the air, which is in the tube *a*, *b*, of the apparatus, Fig. 4, *A*, (our Fig. 5.) is alternately condensed and rarified by speaking into it (or by singing or introducing the tones of an instrument), a movement of a membrane closing the smaller end of the tube is produced, corresponding to such condensation or rarefaction. The lever *c*, *d*, follows the movements of the membrane, and opens and closes (*öffnet und schliesst*) the galvanic circuit (*kette*) at *d*, *g*, so that at each condensation of the air in the tube the circuit is opened, and at each rarefaction the circuit is closed (*ein oeffnen und ein Schliessen erfolgt*)."

The receiving apparatus used in connection with this form of transmitter was quite different in its construction from that employed in connection with the transmitters already described.

Prof. S. P. Thompson, in his work on the Telephone, figures the apparatus shown in Fig. 6, on the authority of Mr. Horheimer, a mechanician who aided Reis in the construction of the apparatus. The platinum contacts *c*, and *b*, placed as shown, had their contact pressure regulated by means of the adjusting screw *h*, the contact *c*, was connected to the strip *g*, of spring brass. The wooden case *a*, *b*, differed in no respect from that formerly employed.

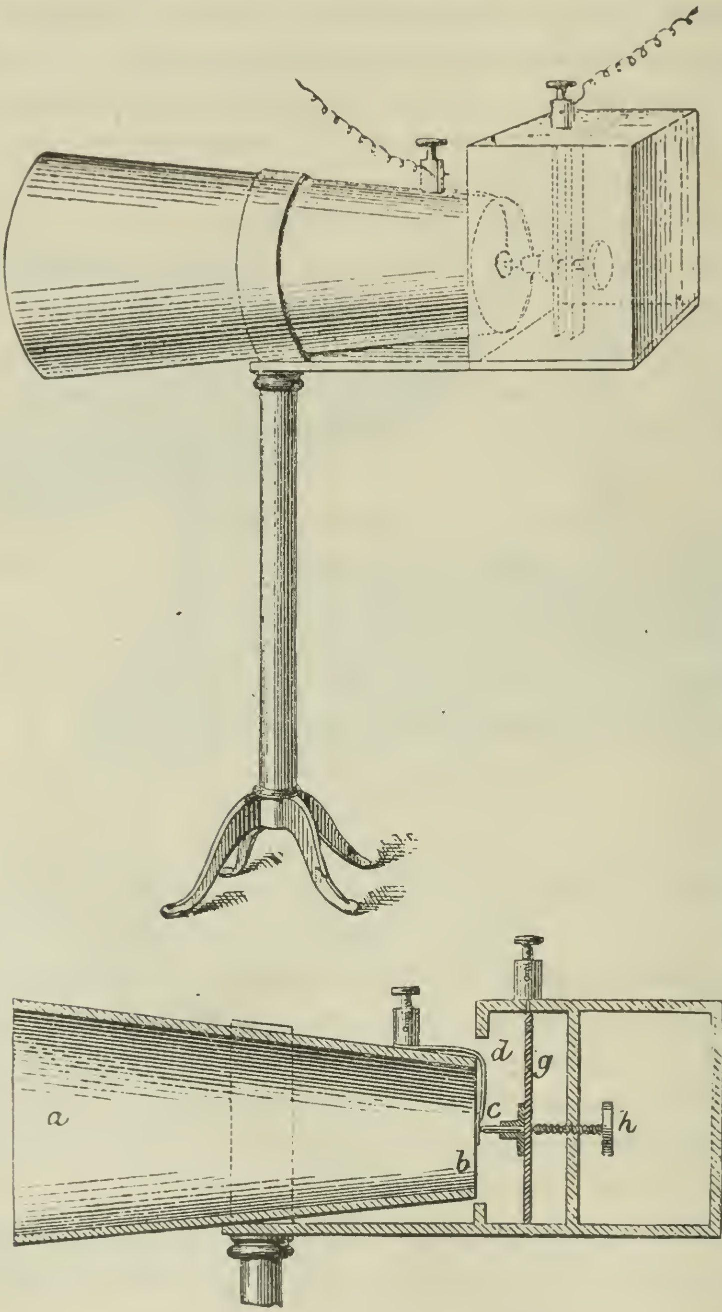



FIG. 6.—The Reis (Horheimer) Transmitter.

This apparatus appears to have been very compact, and doubtless was capable of yielding excellent results.

The form in which Reis left the transmitting apparatus at the time of his death is shown in Fig. 7, connected with a receiving apparatus. This is the form in which it was best known in cabinets of philosophical apparatus outside of Germany. The author is indebted to Müller-Pouillet's "Lehrbuch der Physik und Meteorologie" for the cuts.

The mouth-piece *S*, Fig. 7, was provided with a flaring end and passed into one side of a hollow square or rectangular box *A*. A membrane of bladder is stretched over a circular aperture in the hinged lid of the box. A small platinum strip secured to the centre of the diaphragm is connected with the binding post *a*, by means of the platinum strip *f*. The piece, *h g i*, of metal, has one end resting on the metal pillar *l*, while its other end *i*, is provided on its under side with a platinum point that dips into mercury contained in the hollow pillar *k*. At the angle *g*, of this metallic strip, is a small platinum pin *p*, that rests in contact against the platinum piece secured to the centre of the diaphragm. The mercury in *k*, is in electrical connection with the binding post *l*.

This form of transmitter, therefore, like the others, was dependent on the variations produced by the sound waves in the degree of contact of the platinum points placed in the circuit of a battery.

The transmitting apparatus as left by Reis was provided with an electro-magnetic call. In the model of the Reis telephonic apparatus, for philosophical cabinets, as constructed by Koenig, of Paris, this magnetic call is made in the shape of an electro-magnet with an ordinary hand key for making and breaking the circuit of the same. In Plate I, are shown photographic views of such transmitting apparatus, furnished by Koenig in 1874, for the Smithsonian Institute, Washington.

This apparatus was designed for the purposes of a call. It is thus described by Reis in a prospectus he prepared to accompany his apparatus: "As regards the telegraph apparatus placed at the side, it is clearly unnecessary for the reproduction of tones, but it forms a very agreeable addition for convenient experimenting. By means of the same, it is possible to make oneself understood right well and certainly by the other party. This takes place somewhat in the following manner: After the apparatus has been completely arranged, one

convinces oneself of the completeness of the connection and the strength of the battery by opening and closing the circuit, whereby at *A*, the stroke of the armature is heard, and at *C*, a very distinct ticking.

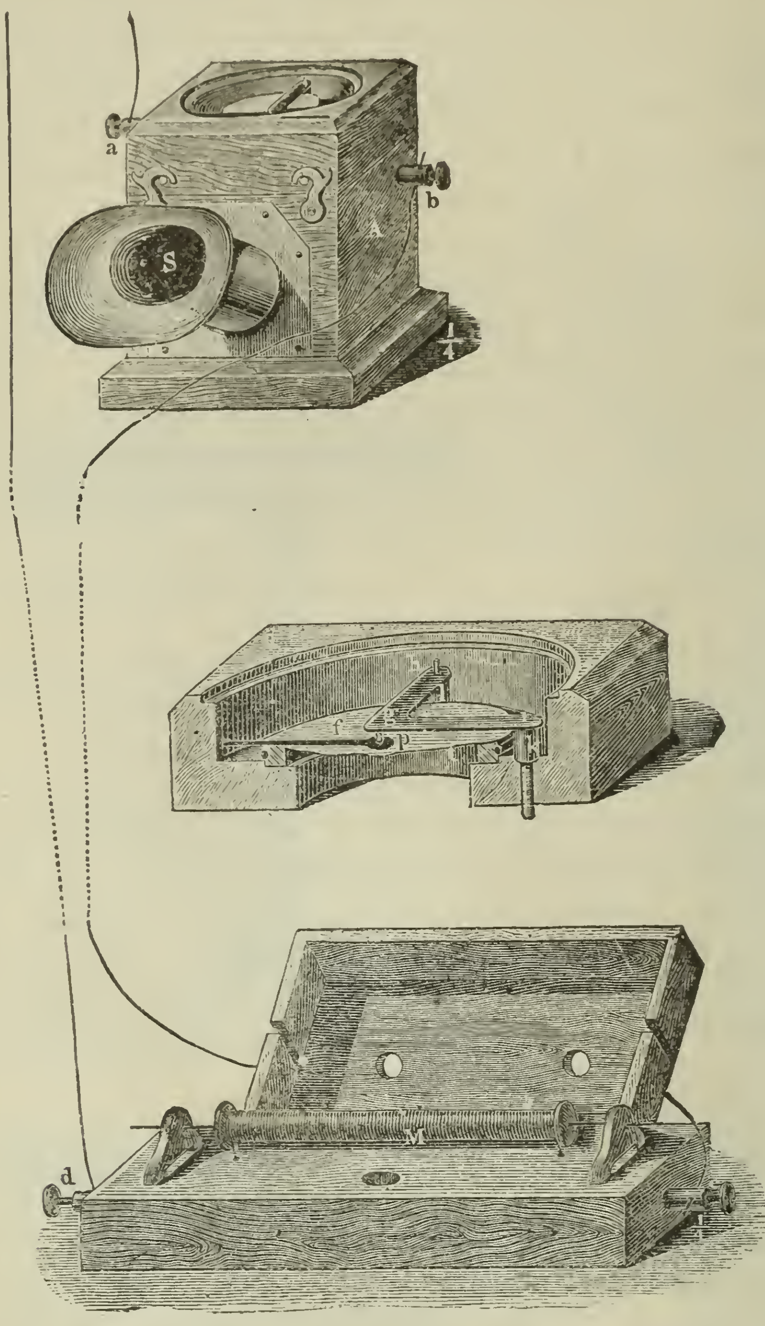
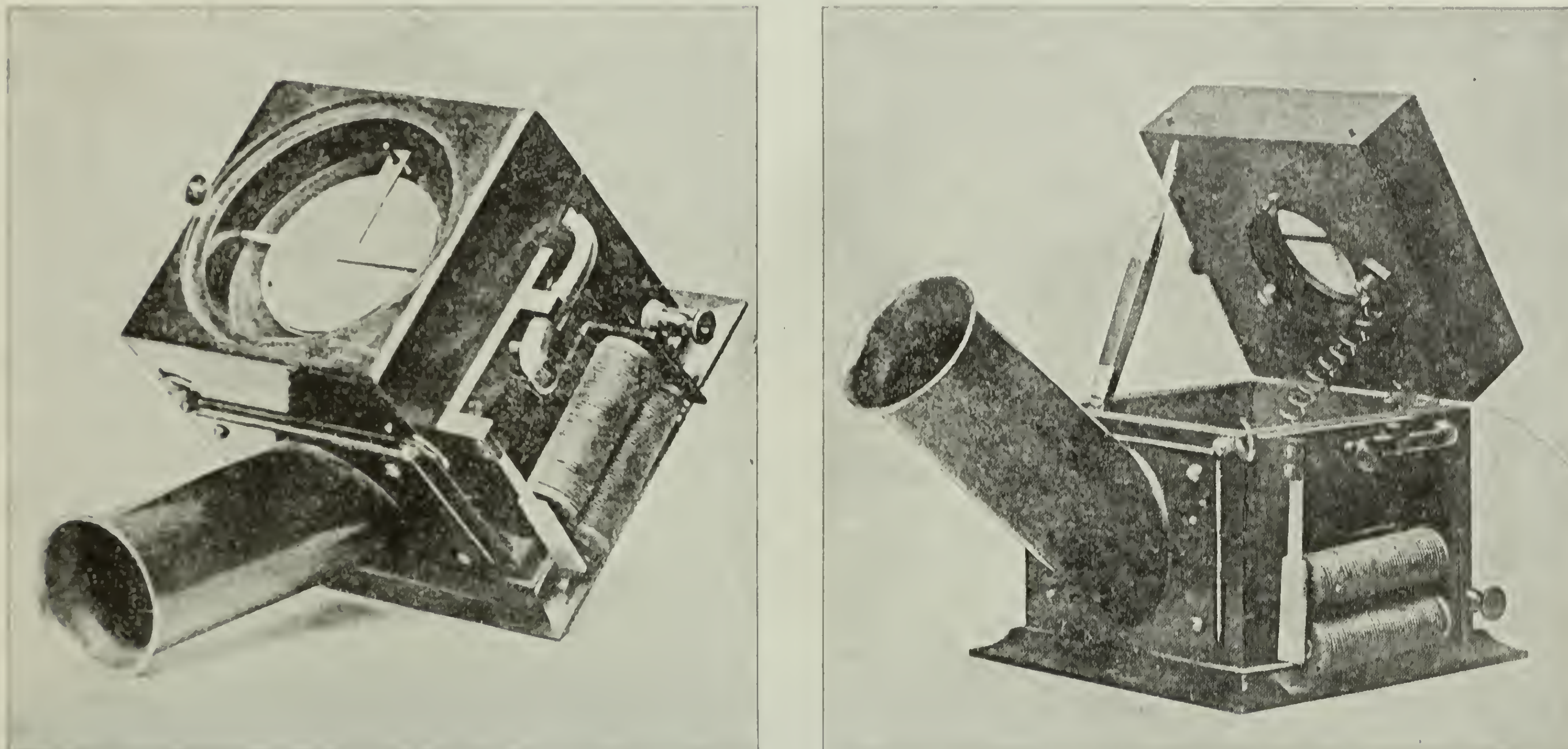
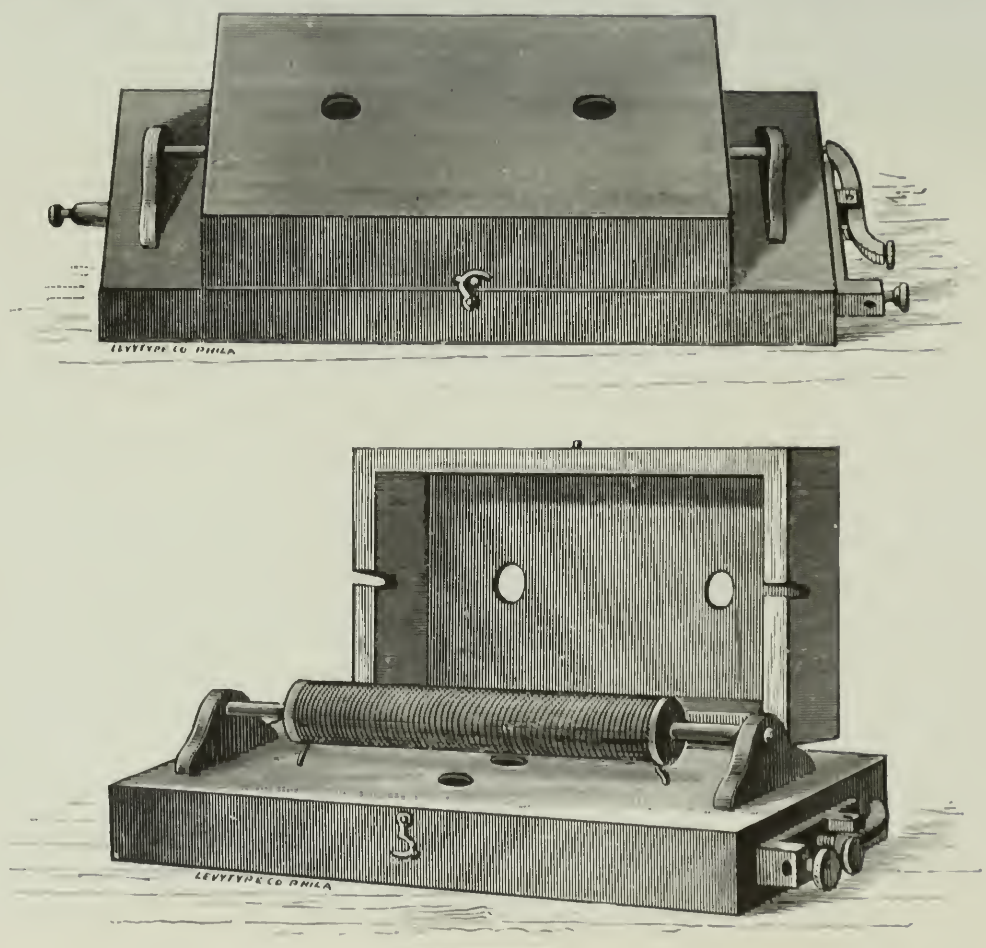



FIG. 7.—Reis's Cabinet form of Transmitter.

"By rapid alternate opening and closing at *A*, it is asked at *C*,



*THE REIS (KOENIG) TRANSMITTER. SMITHSONIAN MODEL.*




THE REIS (KOENIG) RECEIVER. SMITHSONIAN MODEL.

whether one is ready for experimenting, whereupon $C$, answers in the same manner.

"Simple signals can by agreement be given from both stations by opening and closing the circuit one, two, three, or four times; for example: 1 beat = sing, 2 beats = speak, etc."

Reis employed various forms of receivers. His earlier forms, as well as the one he appears to have finally adopted when he placed his instruments before the world, is that shown in connection with Fig. 7. This form consisted essentially of a coil, $M$, of insulated wire wrapped around a core of soft iron or steel. The ends of this coil were placed in the line circuit joined, as shown in the figure, at one end to $b$, and connected at the other end to $a$, through the poles of a suitable voltaic battery.

When, therefore, the speaker spoke into the mouthpiece at $S$, the diaphragm was set into vibration and produced variations in the contact between the platinum point that caused corresponding variations in the current flowing through the coil $M$, at the receiving station. These variations in the current produced movements in the iron core of $M$, that reproduce the sounds causing them. The hollow, resonant case surrounding the core of $M$, serves as a sounding-board to strengthen the tones of the receiver.

We again quote from the translation of the article in the *Jahresberichte* for 1860–1861, already referred to. It will be remembered that Reis is speaking of his "bored-block transmitter," shown in our Fig. 3. Its action was, however, quite similar with that of the transmitting apparatus shown in Plate I. This transmitter was connected with a receiver similar to that shown at the bottom of Fig. 7.

"If new tones or combinations of tones, are produced in the neighborhood of the cube, so that waves of sufficient strength enter the opening $a$, they will set the membrane $b$, in vibration. At the first condensation the hammer-shaped little wire $d$, will be pushed back. At the succeeding rarefaction it cannot follow the return-vibration of the membrane, and the current going through the little strip (of platinum) remains interrupted so long as the membrane, driven by a new condensation, presses the little strip (coming from $p$), against $d$, once more. In this way each sound-wave effects an opening and a closing of the current.

"But at every closing of the circuit the atoms of the iron needle lying in the distant spiral are pushed asunder from one another

("Müller-Pouillet, Lehrbuch der Physik," p. 304, vol. ii, 5th ed.). At the interruption of the current the atoms again attempt to regain their position of equilibrium. If this happens then in consequence of the action and reaction of elasticity and traction, they make a certain number of vibrations, and yield the longitudinal tone of the needle. It happens thus when the interruptions and restorations of the current are effected relatively slowly. But if these actions follow one another more rapidly than the oscillations due to the elasticity of the iron core, then the atoms cannot travel their entire paths. The paths traveled over become shorter the more rapidly the interruptions occur, and in proportion to their frequency. The iron needle emits no longer its longitudinal tone, but a tone whose pitch corresponds to the number of interruptions (in a given time). But this is saying nothing less than that the needle reproduces the tone which was imparted to the interrupting apparatus.

"Moreover, the strength of this tone is proportional to the original tone, for the stronger this is, the greater will be the movement of the drum-skin, the greater therefore the movement of the little hammer the greater, finally, the length of time during which the circuit remains open, and consequently the greater, up to a certain limit, the movement of the atoms in the reproducing wire (the knitting needle), which we perceive as a stronger vibration, just as we should have perceived the original wave.

"Since the length of the conducting wire may be extended for this purpose, just as far as in direct telegraphy, I give to my instrument the name "Telephone."

In Plate II is shown the form given by Reis, in the receiving apparatus as constructed by Koenig, of Paris. It will be seen to be essentially the same as in the form taken from "Mueller-Puillet."

The cuts shown in Plate II are reproductions from photographic views taken of the telephonic apparatus furnished the Smithsonian Institute by Koenig in 1874. They are companion instruments to those shown in Plate I. The resonant case is made of thin elastic wood. The magnetic call and telegraphic key are seen on the side of the apparatus.

It is very evident, in even casually examining this form of apparatus, that the resonant call is very badly disposed to receive the slight movements of the iron or steel core of the instrument. Instead of placing the rod with its end firmly against the sounding-box, it rests on its side, near its ends, on the wooden supports, in the position shown. This probably accounts for the hinged top of the case having

slots cut in its lower edge, and being firmly held against the iron core by means of the latch.

A preferable form of receiver shown in Fig. 8, is known as the violin receiver.

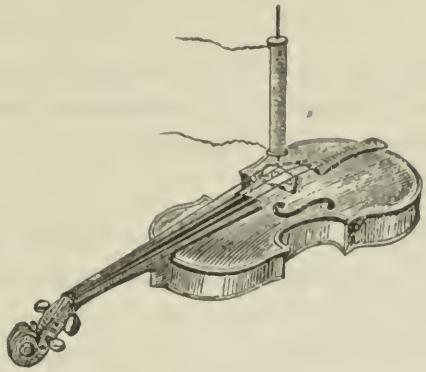


FIG. 8.—Reis's Violin Receiver.

The violin receiver was one of the earliest forms of receiver employed by Reis in his experiments. The original of this form of apparatus is now in the possession of the Garnier Institute, in Germany.

In the description of the Reis apparatus by Inspector Legat, a form of receiver was employed quite distinct from those already described.

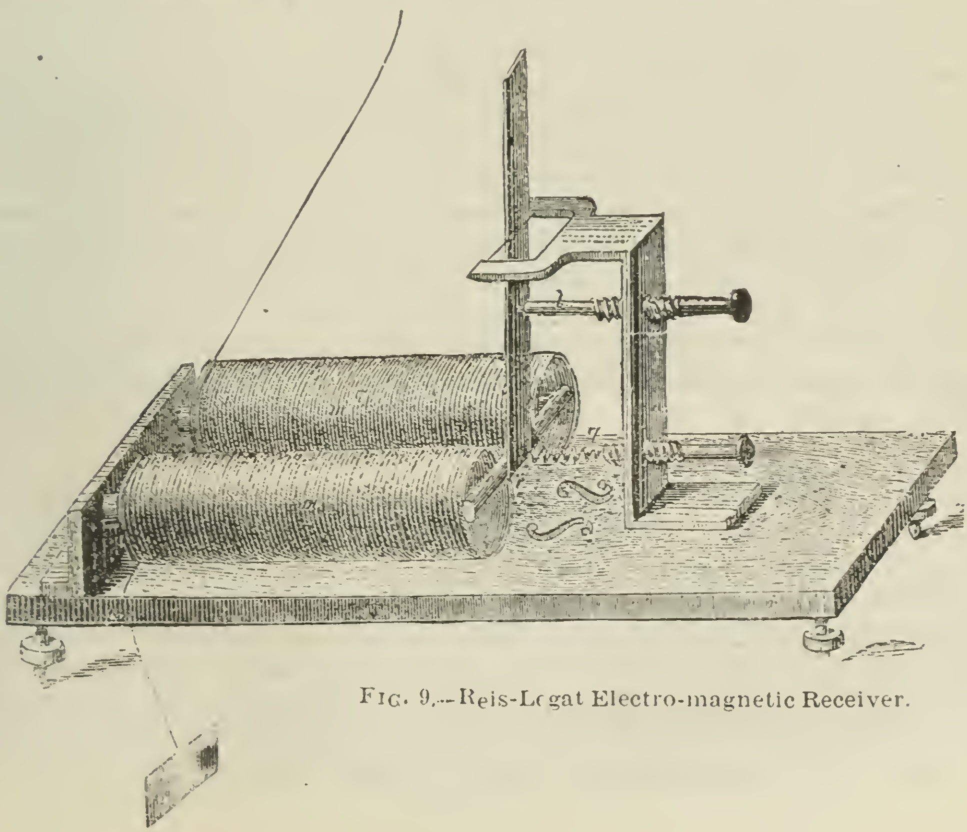


FIG. 9.—Reis-Legat Electro-magnetic Receiver.

In this form of receiver the electro-magnet, *mm*, has its coils placed in the circuit of the transmitting apparatus shown in connection with Fig. 5, one terminal passing to earth. This magnet is placed as shown and firmly attached to the sounding board, *n*. An armature, attached to a long, but light and broad lever, *i*, faces the poles of the electro-magnet, *mm*. The lever, *i*, which bears the armature at its lower end, is suspended after the manner of a pendulum, from the upright standard, *k*. The regulating screw, *l*, and spring, *q*, are furnished for the regulation of its motion.

When now the sound waves impinging against the membrane of the transmitting apparatus produce variations in the intensity of the electrical current traversing the circuit, the magnetization and demagnetization of *m*, *m*, produce corresponding vibrations in its armature, which vibrations are communicated to the air surrounding the apparatus, both directly by the armature itself, and indirectly by the beam, *i*, connected therewith.

CENTRAL HIGH SCHOOL,
PHILADELPHIA, June 10, 1885.

(To be continued.)

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A GREAT WATER-SPOUT.—A French journal describes an enormous water-spout which was formed at the junction of the rivers Vannes and d'Auray. In spite of the violent west wind it followed the channel of the river northwards for a distance of about 4 kilometres, continually increasing in volume. The enormous mass of water with a height of at least 30 metres was traversed by the rays of the sun so that it appeared like an immense prism with its brilliant colors admirably displayed against the dark background of the sky. A superb canopy of a dazzling whiteness crowned its summit and at the base a long train of yellowish foam extended for a considerable distance over the dark green water. After an interval of about twenty minutes the spout suddenly burst with a clap of thunder.—*Les Mondes*, Sept. 18, 1884. C.

CONTRASTS OF COLOR.—Chevreul after referring to his discovery of the simultaneous contrast of colors in 1828, reports the following conclusions: Thomas Young's theory of three primitive colors, red, green and violet, cannot be admitted unless good reason can be shown for excluding the yellow from the primitive list, and unless it can also be shown that the contrast of shades and colors has no other basis than those of simple mixture. Although the principle of contrasts has been discovered since Newton's day, all the distinctions of shade which he pointed out are in thorough accordance with that principle.—*Comptes Rendus*, May 26, 1884. C.

# Book Notices.

Medical Directory of Philadelphia, Pennsylvania, Delaware, and the Southern half of New Jersey. Edition for 1885. Pp. 400. P. Blakiston, Son & Co.

This directory is a great improvement over any directory of its kind that has been issued. In its four hundred pages are found everything pertaining to the medical interests of the State and city. It contains lists of the Physicians in Philadelphia, Pennsylvania, and adjoining States, the dentists and druggists of the city, as well as the details required for a good understanding of the organizations, institutions, and State and city matters connected with medicine. The laws of Pennsylvania bearing upon all matters incorporated in the book are a new feature and of great value. The index, material, and type are well arranged to facilitate reference. F.

The Designing of Ordinary Iron Highway Bridges. By J. A. L, Waddell, C.E., etc. New York: John Wiley & Sons, 15 Astor Place. 1885.

This book is one of the few amongst the great number of scientific books annually published which will receive and which deserves full commendation.

It is invaluable to engineers and students, and to some degree also to municipal and county commissioners, upon whom devolves the duty of selecting new bridges.

The information given therein in regard to the designing of pony trusses and through-bridges built upon the Pratt and Whipple systems—the class of bridges of which it specially treats—is the most thorough and the most practical that was ever published.

As a text-book, in this respect, it does not appear possible that it ever will be excelled.

It is a kind of labor-saving book, presenting the essential points in designing the class of bridges spoken of in a clear, tabulated manner, adding, at the same time, sufficient discussion upon the question of stresses to which the different members of the structure are subjected to prevent the book from assuming the character of a dry and monotonous reference-book.

The author, evidently, is a thorough master of the subject of which he writes.

Curve Tracing in Cartesian Co-ordinates. By William Woolsey Johnson. New York: John Wiley & Sons, 1884.

Professor Johnson has given in this small volume an exposition of a method of tracing plane curves, represented algebraically by equations between two variables and of any degree. He considers especially those rather complicated curves which are studied after the conic sections. His method is very elementary; without the use of the calculus. As a mathematical exercise nothing could be better for the student in technical insti-

tutions than interpreting, on a sheet of drawing paper, the curves in question by any method of interpretation.

That a subject which is grasped most fully with the use of the calculus, may be treated in a really satisfactory manner without such aid, we doubt. We cannot understand the persistence, still lingering, which characterizes the efforts made to dispense with the calculus in practice; an instrument that has proved so grandly useful all through applied mathematics. As a matter of fact, some abstruce problems are capable of solution with the most elementary knowledge of mathematics; but what cumbersome, involved reasoning! Practitioners are said to forget their knowledge of the calculus; but they should not: it is a tool which they need to keep ready for use. When the mathematics have been *thoroughly* learned once, they may lay dormant in the mind for quite a period of time, ready to spring into activity on refreshing the memory by a slight review. C. A. E.

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A Simple Rule to Determine the Length of a Pendulum. By G. Morgan Eldridge.

Set down the number of beats that the pendulum makes to a minute as the denominator of a fraction, and 60 as the numerator. Reduce the fraction to its lowest terms. Square the numerator and denominator by multiplying each by itself.

Multiply the length of a seconds beating pendulum, 39·2 inches, by the squared numerator and divide the product by the squared denominator.

The length of a pendulum is not the length to the end of the ball, but from the point of suspension to the centre of oscillation, which is at some distance above the centre of the ball—this distance depending upon the weight of the pendulum rod in proportion to that of the ball.

To illustrate: a pendulum beating 90, the fraction is $\frac{60}{90}$, its lowest terms are $\frac{2}{3}$, which squared is $\frac{4}{9}$; multiplying 39·2 by 4 and dividing by 9 gives 17·42 inches. A pendulum beating 120, the fraction is $\frac{60}{120}$, its lowest terms $\frac{1}{2}$, which squared is $\frac{1}{4}$; multiplying 39·2 by 1, dividing by 4, gives 9·8 inches. A pendulum beating 30, the fraction is $\frac{60}{30}$, its lowest term s $\frac{2}{1}$, which squared is $\frac{4}{1}$; multiplying 39·2 by 4, dividing by 1, gives 156·8 inches.

[This is not intended for the scientist, but for the practical workman who has forgotten the square root—if he ever learned it—who has no idea of the nature of a logarithm, and to whom a formula is Greek. It will be entirely within the range of his comprehension and application, and the results are correct.—E.]

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The Principles of Ventilation and Heating, and the Practical Application. By John S. Billings, M.D., LL.D. (Edinb.), Surgeon in U. S. Army.

The work under consideration is peculiarly characteristic of a class which has appeared of late years in all departments of study, being designed to bridge the chasm that hitherto divided the branches of knowledge commonly distinguished as scientific and practical—distinctions which works like the present tend to obliterate.

The author states that he was actuated in the production of his work by the endeavor to comply with a request for "some plain, practical directions

as to the best methods of arranging the ventilation of a building, to be given, as far as possible, in the form of specifications which can be easily understood by an intelligent builder, and not in the form of abstract mathematical formulas," and, while disclaiming the ability to comply strictly with such a request, and to establish a royal road to knowledge, he has attempted to render the progress less difficult.

That he has succeeded in this laudable effort, a perusal of the work demonstrates: and with a full appreciation of the importance of the subject with which it deals we commend it to the public at large as well as to those specially interested. W. B. C.

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Spon's Mechanics' Own Book: a Manual for Handicraftsmen and Amateurs. London and New York: E. & F. N. Spon, 1885.

This is a compendium of information useful alike to the professional and to the amateur mechanic. The latter will find in it the knowledge which he requires for his particular hobby, whatever that may be, and the former must be rarely skilled in his art if he cannot find in its pages points in his own specialty which have hitherto escaped his research; and when he needs—as every one does sometimes need—to explore kindred branches of art, he will find in this book a guide, a companion and a serviceable friend. G. M. E.

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Physician's Visiting List for 1885. 12mo. Philadelphia: P. Blakiston, Son & Co., Publishers.

This standard book, now in the thirty-fourth year of its publication, and so well known to physicians, calls for a few words of praise, it being the aim of its publishers constantly to add to its excellence without much increasing the size of the book. In addition to the blank leaves, properly ruled for a visiting list, monthly memoranda, etc., we have Marshall Hall's method for treating asphyxia; Sylvester's for producing artificial respiration; a list of new remedies by Dr. Henry Morris, in which cocaine is singularly omitted; the usual dose table: poisons and their antidotes, and the decimal system of weights and measures which we are glad to see is making such headway in scientific medicine, leaving little or nothing to be desired in this indispensable volume for the pocket of the busy practitioner. I. N.

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Bacterial Pathology; a series of papers on the Exhibits at the Biological Laboratory of the Health Exhibition under the charge of Watson Cheyne. 12mo. New York: Industrial Publication Company. 1885.

The scientific as well as popular interest in this subject is so great that it has been thought well to collect the series of papers which have appeared in the London *Lancet*, in this little volume which is literally running over with material for thought and action, by our constituted authorities. The micrococus of pneumonia and the bacillus of typhoid fever and tubercle are briefly described, and illustrated with some excellent wood-cuts. We have also the bacilli existing in milk and butter given, while the pamphlet concludes with the various methods used in the laboratory for cultivation

of the germs and the media employed. The researches of Pasteur, Koch, Formad and others have made this comparatively new subject so important to man, that any attempt to give light and increase knowledge is very important, and the above series of papers form a good introduction to more elaborate works on the subject. I. N.

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## ANNUAL REPORT

### OF THE DIRECTOR OF THE DRAWING SCHOOL OF THE FRANKLIN INSTITUTE, FOR THE SESSIONS 1884–1885.

The Drawing School year, which ends this evening, has been productive of good results, and will compare favorably with past years, except that the number of students has not been up to the average, the general stagnation of business having had its effect on this as on everything else. The system and methods of teaching have been improved, models illustrating the principles of projection have been furnished, a number of standard typical machine models have been supplied, and the collections of prints of geometrical problems, orthographic projections and machine construction, has been largely increased.

The school affords an excellent opportunity for a diligent, attentive and interested student to obtain a knowledge of the principles and practice of drawing, and numerous instances of material advantage arising from it have occurred. The ultimate benefit to any individual depends upon his own capabilities and exertions, the school affording every facility for him to make the most of them. Artisans, mechanics and those connected with manufacturing, have, as a rule, made the best progress; but there have been very few indeed who have not been benefitted. The importance of a knowledge of this branch of technical education is gradually becoming more appreciated and every effort should be made to encourage a study so conducive to the material development of the country, and so in harmony with the genius of the people. The system of this school combines theory and practice, so arranged as to accomplish the most useful results in the least time. * * * * * The custom of granting certificates to those students who have attended four terms is continued, but all those who are really interested in their studies are strongly advised to continue, as very few succeed in obtaining all the possible benefit in that time.

The drawings exhibited this evening present a fair average of the work of the year.

The Free Hand Class shows drawings from the flat and also from casts. The Architectural Class shows designs, plans and details for dwellings, most of which are original and some for use. These classes have been under the instruction of MR. EDWARD S. PAXSON and MR. CLEMENT REMINGTON.

The Junior Mechanical Classes show a course of problems in Plane Geometry, which gives the student, in addition to a knowledge of the problems themselves, a familiarity with the various lines, shapes and magnitudes, an appreciation of the importance of care and accuracy, and a knowl-

edge of the use of instruments. These classes also commence the study of projections, a clear understanding of which is so essential and, at the same time, so difficult to obtain. The use of a series of models, with the object surrounded by transparent planes, has materially aided in elucidating this subject. These classes have been in charge of MR. GEORGE S. WILLITTS and MR. WILLIS H. GROAT.

The Intermediate Classes under MR. CARL BARTH, have gone very thoroughly into Projections, Intersections and Developments, which constitute the basis of exact drawing for mechanical purposes and are of great importance, although usually neglected. In this school much time and attention is given to this branch.

The Senior Mechanical Class under the instruction of the Director Mr. WILLIAM H. THORNE, pursues a course of practical draughting, making working drawings from copies, sketches and models, applying the principles already learned, and giving particular attention to the technicalities and methods best adapted to actual work.

The following students deserve Honorable mention for their attention, industry and progress:

*In the Senior Mechanical Class.*

| | | |
|---|---|---|
| James G. Davis, | Eb. W. Thomas, | J. E. Pugh, |
| Max Uhlmann, | Charles von Berger, | Joseph Herbick. |

*In the Intermediate Mechanical Classes.*

| | | |
|---|---|---|
| F. W. Langell, | J. C. Biddle, | Clarence E. Wood, |
| William H. Schalliol, | J. McEachren, | James F. Deimling, |
| E. Morgan Denney, | George S. Iredell, | W. J. Dignan. |

*In the Junior Mechanical Class.*

| | | |
|---|---|---|
| T. Edward Schiedt, | Samuel Wilson Goodwin, | E. T. Taylor, |
| Charles R. Middleton, | | Franklin L. Kellner. |

*In the Architectural Class.*

| | | |
|---|---|---|
| Rodger M. Coombs, | Thomas W. Draper, | John Dueringer, |
| Bernard Rimer, | Wilbert H. Smith, | George Highley, |
| | Minnie M. Parker. | |

*In the Free Hand Class.*

| | | |
|---|---|---|
| William Himelspark, | Frank Pierce Homer, | James J. Dunn, |
| Mary H. Goudkop, | | William Rothfuss. |

The following students are awarded scholarships from the B. H. Bartol fund, entitling them to free attendance during the next term, beginning September 29, 1885:

| | | |
|---|---|---|
| J. E. Pugh, | T. Edward Schiedt, | Rodger M. Coombs, |
| F. W. Langell, | J. C. Biddle, | William Himelspark. |

They will present themselves to the Actuary at that time and receive their tickets.

The following students having attended the school during four terms, are awarded certificates to that effect:

| | | |
|---|---|---|
| James G. Davis, | Edgar L. Hallowell, | Eb. W. Thomas, |
| J. E. Pugh, | William S. Lawrence, | A. Bonfidis, |
| Max Uhlmann, | Gerhard Walton, | Charles von Berger, |
| Warren Dexter, | Joseph Herbick, | James J. Dunn, |
| Viggo Torbensen, | Bernard Rimer, | Charles Regester, |
| George Highley, | J. H. McCullough, | E. G. Kolb, |
| George McArthur, | John McCoy, | George D. Holt, |
| | George Löwe. | |

The recipients of these certificates ought not to consider that they have completed their education in drawing, but should continue at the school until convinced that they have received all the benefit that is to be derived from it.

WILLIAM H. THORNE,
*Director.*

*Philadelphia*, May 21. 1885.

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# Franklin Institute.

[*Proceedings of the Stated Meeting, held Wednesday, June* 17, 1885.]

HALL OF THE INSTITUTE, June 17, 1885.

WM. P. TATHAM, President, in the chair.

Present—108 members and 9 visitors.

The election of thirteen new members was reported.

Recommendations for the award of the "JOHN SCOTT Legacy Premium and Medal" were reported from the Committee on Science and the Arts, to MORRIS L. ORUM, for his improvement in Locks; ORLANDO W. SPRATT, for his Mercury-Seal Trap; and ISAAC TOWNSEND, for his improved Tent-slip.

The recommendations were severally approved, and the Secretary was directed to communicate the action of the Institute to the Committee on Minor Trusts of the Board of City Trusts.

MR. W. CURTIS TAYLOR read the paper of the evening, "On Composite Photography." The paper, with lengthy discussion thereon, has been referred to the Committee on Publication.

The Secretary's report embraced an account of the recent experiments of Mr. Della Torre, of Baltimore, to determine, by the ingenious device of obtaining an echo therefrom, the proximity of an iceberg or other obstruction in the path of a vessel. The apparatus employed consisted of a musket, to the muzzle of which a speaking-trumpet was attached, and from which

blank cartridges were fired in the direction of passing vessels. The results are reported to have been encouraging.

The Secretary gave a description also of some interesting applications of isochromatic photography for which he was indebted to, Mr. Ives.

To prevent the counterfeiting of bank notes by photo-lithography or photo-engraving, they have been printed in two or more colors, which present a strong contrast to the eye, but come out equally dark in an ordinary photograph, making it impossible to reproduce either design by itself. The Secretary exhibited two examples of this two-color printing, by the American Bank Note Co., which had been submitted to Mr. Ives, to see if they were proof against counterfeiting by means of his isochromatic process. One was printed in dark red and light lemon-yellow, the other in dark blue and light lemon-yellow. Mr. Ives succeeded in obtaining good photographs of the designs printed in red and blue, without showing the yellow at all. In ordinary photographs, made for comparison, the light yellow comes out as dark as the red, and darker than the blue.

The Secretary likewise referred to the recently published results of investigations by Prof. Edward S. Wood, of the Massachusetts State Board of Health, which exhibit an alarming and indiscriminate use of arsenic in various branches of manufacture.

He read a copy of a letter of DR. BENJAMIN FRANKLIN, which had lately been brought to light, in which were some highly interesting suggestions respecting the introduction of canals into the Province of Pennsylvania. The letter is addressed to S. RHOADS, Esq. (who was Mayor of Philadelphia in the historic year, 1776), and is dated London, August 22, 1772. It was discovered among the family relics of a descendant of Mr. Rhoads, and who is a member of the Institute.

The Albo-Carbon Light, F. Hickman's Hose-Coupling, and H. Weindel's Steady-Blast Air Pump were exhibited and described.

MR. OTTO LÜTHY exhibited and remarked upon some specimens of molasses and sugar grown upon the recently reclaimed swamp lands in Florida, known as the "Everglades," which a party of Philadelphia capitalists have for some years been engaged in draining. Several millions of acres have already been drained, and soil and climate are reported to be admirably adapted for growing the sugar cane.

The following, on Prof. Houston's motion, numerously seconded, was adopted:

*Resolved*, That the Franklin Institute respectfully requests the Board of Health, of the City of Philadelphia, to take such measures as may be necessary to prevent the pollution of the Schuylkill river by the National Encampment about to be held at Fairmount Park.

Adjourned.

WILLIAM H. WAHL, *Secretary.*

# LIST OF BOOKS

## ADDED TO THE LIBRARY TO MARCH 1, 1885.

(Concluded from page 504.)

Newton, Mass. Auditor's Annual Report for 1883. From the Mayor.

Newton, Mass. Rules and Regulations of the Board of Health, and Ordinance 24. 1884. From the Board.

New York State Survey. Report for 1884. Albany, From the Survey.

O'Connor, C. Forging and Finishing of Marine Crank-Shafts. Manchester. From Frederick Walthen.

Ordnance Bureau. Annual Report of the Chief for 1884. 2 copies. Washington. One presented by the Bureau, and one by Dr. W. H. Wahl.

Ores and Minerals of Industrial Importance occurring in Alabama. By E. A. Smith, State Geologist. Montgomery, Ala., 1884. Presented by the Author.

Patent Office, British. Abridgements relating to Agriculture. Div. 3. Agricultural and Traction Engines. 1618–1866.

Alphabetical Index for 1883, and January–June, 1884.

Catalogue of the Library. Part 2.

Subject-Matter Index for 1883, and January–June, 1884.

Specifications and Drawings. Nos. 701 to 3000, and 3501 to 4700. 1883.

From the Hon. Commis'rs of Patents, through Mr. F. Ransom, London, Eng.

Patent Office, United States. List of Patentees and Inventions for Quarter ending September, 30th, 1884.

Specifications and Drawings of Patents. January to August, 1884.

Presented by the Commissioner of Patents.

Pennsylvania, Agriculture of. 1884. Harrisburg, 1885. From Captain Milton P. Peirce.

Pennsylvania Hospital, Addresses by Dr. T. G. Morton and J. B. Garrett on the Unveiling of West's Picture, Christ Healing the Sick. Presented by the Board of Managers.

Pennsylvania. Second Geological Survey Anthracite Coal Fields. Harrisburg, 1885. From the Survey.

Pennsylvania. Second Geological Survey. County Geological Maps. Harrisburg, 1885 From the Survey.

Pennsylvania State College, Agricultural Bulletins. No. 10. Presented by the College.

Philadelphia and Reading Railroad Company. Report of the President and Managers for 1884. Philadelphia. From the Company.

Philadelphia Society for Organizing Charity. Sixth Annual Report of the Board of Directors. Presented by the Board.

Photographic News. A Weekly Record of the Progress of Photography. By G. W. Simpson. Vols. 10–12. London: Piper & Carter. 1866–1868.

Photographic Society of London. Journal. Vols. 1–14. London: Taylor & Francis. 1854-1869.

Pilot Charts of North Atlantic Ocean. January and March, 1885. Presented by Hydrographic Office, U. S. Navy, Philadelphia.

Porter, Robert P. Protection and Free Trade To-day. Boston, 1884. From Dr. William H. Wahl.

Public Ledger Almanac for 1884-1885. Philadelphia. From George W. Childs.

Practical Mechanics' Journal. N. S. Vol. 2. London. Longman, et al. 1857–58. This Volume completes the set.

Postal Microscopical Society. Rules and Names and Addresses of Members. Bath, 1884. From the Society.

Pozzi, G. Dictionary of Physics and Chemistry. Milan, 1820–1830.

Rand, A. C. New Rock Drill without Cushions. 1884. From American Institute Mining Engineers.

Richmond, Indiana. Annual Financial Reviews of Reports of City Officers. 1881–2. From the Mayor.

# JOURNAL

OF THE

# FRANKLIN INSTITUTE

OF THE STATE OF PENNSYLVANIA,

FOR THE PROMOTION OF THE MECHANIC ARTS.

Vol. CXX. AUGUST, 1885. No. 2.




## COMPOSITE PHOTOGRAPHY.*

By W. Curtis Taylor.

Composite Photography is the combining of a number of photographic images of similar objects in such a manner as to produce one single image, representing the characteristics of all. In other words, it is a method of getting the average looks of things having a typical relation. The method was first put into practice by Dr. Francis Galton, F.R.S. The aspects of countenance supposed to indicate certain diseases, he expected to represent by this means. He extended the idea in attempting to represent family types, criminal types, etc., conceiving that an average of many individual faces would sink minor differences and preserve the grand peculiarities of their respective classes.

To Mr. Walter R. Furness, of this city, belongs the credit of being the first here to employ this process. This was early in this year, for the copious illustration of a valuable work on Shakespeare portraiture, soon to be issued by Lindsay & Co. Mr. Furness's work is the first in the world, I believe, to use Composite Photography analytically, for the creation of a reliable historic likeness.

* Read before the Franklin Institute, June 17, 1885.

So much for the idea and intention of composite photography. Next, how is it produced?

It is to be supposed that everybody here knows enough of photography to understand that, to produce an effect on the sensitized plate in the camera, capable of being developed afterward into a perfect image, a given exposure, longer or shorter, is required. Then it will readily be conceived that a fraction of this exposure will produce an effect proportionately faint; and that if two or more such effects be caught on the plate, one upon another, the result will be a compound of all; and if the objects were of nearly equal intensity and the separate exposures about the same, no one of these objects would preponderate above another in the combined result. For it must be remembered that the impression, before it is developed, is simply an invisible chemical change wrought on the plate, and is not of the nature of a picture having thickness and density. I make this remark here because some persons have asked whether the last impression made on the negative would not dominate those under it. In this gross sense there is no such thing as "over" or "under" in such an instance.

The exact manner of getting these impressions superposed on the sensitive plate I will now try to show. In the first place the photographs to be combined are all reduced as near as may be to the same size. Those portions which it is most important to fit are brought into juxtaposition by the following means. In the case of human portraits, the line of the eyes is made to correspond with a thread stretched across a light open frame; and the centre of the space between the eyes to correspond with a thread at right angles with the first. These threads are permanently attached to the frame, which also has pierced through it, at its corners, four small holes. A block is provided with four pins agreeing with the holes in the frame. We now take one of the unmounted photographs to be combined, and laying the frame over it so as to make the threads correspond with the eyes in the portrait, we puncture the photograph through the holes in the frame and slip it by means of these holes upon the pins of the block. This is done successively with all the photographs to be copied. If they have been made to scale and carefully wired, the eyes in the whole pile will be very nearly one above another, and the mouths also will match as well as circumstances will admit.

The block with the suspended photographs is now placed before the camera, and each photograph is exposed, in turn, for such a portion of the

whole time as would be required for one good exposure as may be determined by the number of the pictures combined. In the case of the first series of 17, which will now be shown, I think each individual had but 5 seconds. This being but one-seventeenth of the time, it is impossible that any of these men is shown in the composite to be next placed on the screen. But before we remove our friends, we must introduce them. They are the officers of the American Association for the Advancement of Science, for this present year. All but three are from originals we made last summer. You know most of them by reputation. They are:

Profs. Cope, Lesley, Newton, Hilgard, Putnam, James Hall, Langley, Morse, Eaton, N. H. Winchell, Wormley, Thurston, Eddy, Springer, John Trowbridge and Newcomb.

We have in this composite a new man whom the world has never seen; and, from the nature of his make-up, we can criticise him to his face without making any hard feelings. He is a "nice-looking" fellow, but I do not think he looks particularly "smart," as we Americans say. From this composite you will see that the average scientist does not live behind spectacles. The average scientist, also, does not part his hair in the middle. It is true he has a rather giddy shirt front, but that only shows the want of uniformity among his components in the matter of dress. But you ought to hear what some of him say about him.

Prof. Cope, in his sententious way, says he looks "silly." Prof. Thurston says he is "a pretty good-looking fellow." He agrees that he does not look strong in any one direction, but thinks he might do well if he had a powerful incentive, and at any rate has not the narrow look of a specialist. Prof. Morse says: "Your remarks concerning the absence of force in the picture interested me greatly, and I do not see why you are not justified." Prof. Winchell says: "The man you make by mixing us all up seems to have no strong trait of character. He is an average Anglo-Saxon of the nineteenth century, and seems ready, if waked up to it, to take up any business; but he don't look as if he would undertake it without strong impelling circumstances."

On the other hand, a letter from Sir Wm. Thomson, received this week, says: The composite of the "seventeen officers of the A. A. A. S. seems like Prof. ——— (naming one of them). Indeed, when we

first saw it, without noticing it was a composite, we thought it was he."

When we come to consider, later on, the results of composite photography and the limitations of its usefulness, there will be something more to say about the weakening effect of these averages, which I have here only hinted at.

Our next series is not a pleasing one to the eye, but has interest as representing the very opposite of the cast of countenance we have been considering. We are allowed for this purpose the use of some of the portraits from the Rogues Gallery, at Fifth and Chestnut streets. There are four representatives of the ten used in making the composite which is to follow. It did not seem necessary to show the whole of the originals employed. One of these men was a murderer. I think you will have no difficulty in picking him out. The rest were burglars and general thieves.

Looking, now, at the composite from these brutal and mean faces, we shall see that, just as the composite of the wise men did not look so very wise, so that of these vile men does not look quite vile. This new man has an ignorant, stolid, and, as one has said, a "hunted" look, but nothing worse. If, then, it is the case that this averaging process, however entertaining, has limits to its scientific value in one direction, we must look farther to establish its claims to serious consideration. Dr. Galton, himself, says that this process has a beautifying effect upon indifferent-looking human subjects. Just to this extent, then, it fails of useful application.

*Why* this process should fail of useful application where its subjects are multiform, is not hard to perceive. It is well understood that we can make waves of water and waves of sound interlock so as to produce rest and silence. And thus, if we take away the strong individuality that marks prominence of character, we take away its forcefulness. In our new scientific friend, to use a figure from the phrenologists' lingo, we have a man without bumps. The grand part of one man's head happening over the inferior part of another's has done leveling work; and in these representations the average of the great men is not great, and the average of the vile men is not vile.

But when we work with distinctly marked groups of closely allied objects, then there is no drawback to the scientific and historical value of this method. Such an example you will find in our next series.

Here we have seventeen original and contemporaneous pictures of

Washington; seven being profile views of the face, five three-quarter faces and five midway between these. We are indebted to Mr. W. S. Baker, of this city for the use of these valuable originals, many of which without his kindness would have been practically inaccessible.

The earnest interest attaching to the three Washingtons, the composites now placed before you, has been recognized by the Smithsonian Institution, by the National Army Museum, by two distinguished authors who have published works on Washington portraiture, and by various scientific correspondents.

In looking over these heads of Washington, by fourteen independent artists, you cannot fail to be impressed with the strange diversity among them. Some you would utterly fail to recognize. Yet they are all by careful artists, who must have had reputation at the time, and who testify as eye-witnesses. But how different their testimony!

Now just as in legal investigations we get at the truth by putting together what all the witnesses say, and rejecting the unsupported contrarieties of the individuals among them, so here. What one artist depicted and the others did not, is sunk out of sight, being so faintly shown in the composite. Four-fifths of the photographic exposure is too much for the one-fifth. The burden of the testimony is all against that artist. For example, Stuart's, with its short, bunchy nose, which has long been the popular Washington, should now be discredited. It is not nearly so like the average as Trumbull's; which, indeed, has always been the favorite with a few, but has never been popularized.

It is a remarkable demonstration of the value of this method, so applied, that while the individual Washingtons in each of these three groups bear so little resemblance to each other, their respective composites do represent one and the same man. These composites are now placed side by side, that you may see that each group of artists, *as a group*, tells the same story; and doubtless, as it is the sifting of the testimony of fourteen eye-witnesses, it is a true one.

I consider this remarkable unanimity the crowning feature of these newly created likenesses of the Father of his country; and an earnest of other good things that may be hoped for from this new department of photography.

## DISCUSSION.

THE PRESIDENT:—In your remarks about the disagreement among these separate heads of Washington, do you think you kept sufficiently

in mind the years that separated them? Some of these were made about 1779, and others not till 1798. During that time, too, Washington lost his teeth, and that will account for the mouth being different later in life, as in Stuart's.

Mr. TAYLOR:—Yes; but that will not account for Stuart's nose being shorter. And as to age, the earlier pictures shown here do not seem to differ so much in that respect as in the permanent characteristics by which we identify individuals while we make allowance for their advancing years. No doubt the change in the mouth made a marked difference, but I think that would not control our estimate of the face as a whole.

Mr. W. B. COOPER:—Might not a composite be made as well by making a glass positive directly from the negatives?

Mr. TAYLOR:—Yes, just as well; and that is the method of Prof. Pumpelly, of Newport, who has sent me a very fine positive, which I would have exhibited here to-night if permission had been given. But then you fail in that way of getting a negative ready for all manner of multiplication. By the method described here to-night you get your composite once for all, ready to make positives either on glass for the lantern or on paper for more general use.

Mr. G. B. LEE:—Would not the fact of getting the separate pictures from paintings, where the colors falsify the result, account for some of the disagreements among the copies of Washington heads?

Mr. TAYLOR:—It would undoubtedly, if paintings had been used; but all the copies are from engravings, except one of a Houdon which I made directly from the marble bust. If it were necessary to copy paintings, the isochromatic process, described here lately by Mr. Ives, should be used.

Prof. HOUSTON:—I would like to ask Mr. Taylor if there should not be a difference of time in the separate exposures? It seems to me that a photograph or engraving having strong effects should not receive so much time in the copying as a weaker one.

Mr. TAYLOR:—What Prof. Houston says is, in one view, entirely correct, and was a matter of consideration with us in making these composites. Some were tried with the allowance he suggests. But in presenting the subject to scientific bodies I thought it would be better to be able to say that exactly the same time was given to each, as that threw out of the estimate supposable errors of judgment in apportioning the time. I may say, however, that our experiments with time,

with the view named by Prof. Houston, did not materially change the effect.

Mr. ——— :—I notice there is an elongation of the faces in the Washington composites. Why is this?

Mr. TAYLOR :—There is nothing in the process tending to elongate the faces. (After the meeting it was stated that the member making this inquiry sat very much to one side of a line at right angles with the screen, and saw the pictures obliquely. An animated discussion ensued on the relative intellectual indications of long and round heads.)

Mr. WM. TILGHMAN :—Would not the last impression on the plate show itself more strongly than the rest in these composite pictures?

Mr. TAYLOR :—The answer to this very natural inquiry is in the paper I had prepared; but it was probably overlooked in the reading, and I am glad the gentleman has asked it. No, it can make no practical difference, which image goes first or last on the plate, for in any material sense of an image, having thickness, no such thing is produced until the plate be developed. You might place a thousand of these effects—which are nothing but actinic influences—on a plate, and take it from the camera to the dark room, and you would be unable to see anything on the glass except the original film which received the impressions.

THE PRESIDENT :—Did you try different orders of placing these impressions on one another?

Mr. TAYLOR :—Yes; though we were satisfied, by theory, that there should be no difference, we tried it and found none.

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MEASURING TEMPERATURES BY THE TELEPHONE.—Dr. Lenz has described in the Bulletin of the St. Petersburg Academy, an ingenious application of the telephone to the measurement of temperatures at a distance. Suppose two stations united by two wires, one of iron, the other of silver, soldered at the two extremities. If the soldering of station M is different from that of station N, a thermo-electric current circulates through the wires. On introducing a telephone and an interrupter into the circuit, the telephone will continue sounding until the observer at one of the stations raises or lowers the temperature of his joint so as to make it identical with that of the joint of the other station; the current then ceases, and the telephone becomes silent.—*Génie Civil; Les Mondes*, Nov. 1, 1884. C.

# TRANSPORTATION FACILITIES OF THE PAST AND PRESENT.*

By William Barnet Le Van.

At the December meeting of the Institute I had the honor of reading a paper on "Modern Railroad Facilities," and, from the comments of the press, both at home and abroad, it would appear that certain statements made therein are not generally known or admitted. I therefore propose to present a few leading facts bearing on the subject of this paper, in the order of their occurrence.

## CANALS.

Pennsylvania may properly claim the credit of being the mother of the Internal Improvements of the United States, which commenced one hundred years ago.

In the year 1787 authority was asked of the Provincial Legislature for the right to open a water communication between the Schuylkill and Susquehanna rivers, which was granted for what is known as the Union Canal.

In 1791 this work was commenced, and in 1794 one of the western sections, four miles in length, was completed and opened to navigation. From this period the further prosecution of the work was suspended, and it was not again resumed until the year 1816, when a newly organized company assumed its management, under whose direction the canal was completed, and open to traffic in 1824. This is, briefly, the history of the "Union Canal."

It is interesting, and some of my hearers may be amused to know that the origin of the canal system, which has attained such astonishing growth in the United States, can be traced to the little insignificant canal, of about three-fourths of a mile in length, formed by cutting off the bends and deepening the channel of Dock Creek, in Philadelphia. This work, which modern improvements have entirely obliterated, was executed more than one hundred and fifty years ago, *and was the first canal executed in Pennsylvania, or in the Colonies.*†

* Read at the Stated Meeting of the Franklin Institute, May 20, 1885.

† In connection with the history of the progress of internal improvements in the United States, especially with the development of the means of intercommunication, it may be of interest to reproduce a letter from Dr.

(ROADS) TURNPIKES.

The road leading from Philadelphia to Lancaster, made nearly one

FRANKLIN to a prominent citizen of Philadelphia. The letter relates to the introduction of canals into the Province of Pennsylvania It is addressed to S. RHOADS, Esq. (who was Mayor of Philadelphia in the historic year 1776), and is dated London, August 22, 1772. It came to light among some papers of Mr. Rhoads, which passed into the possession of one of his descendants, who is a member of the Franklin Institute, and who has politely permitted this use to be made of it. It is reproduced herewith:

"LONDON, Aug. 22, 1772.

"DEAR FRIEND:—I think I before acknowledg'd your Favour of Feb. 29. I have since received that of May 30. I am glad my Canal Papers were agreeable to you. I fancy Work of that kind is set on foot in America. I think it would be saving Money to engage by a handsome Salary an Engineer from home who has been accustomed to such Business. The many Canals on foot here under different great Masters, are daily raising a number of Pupils in the Art, some of whom may want Employment hereafter, and a single Mistake thro' Inexperience in such important Works, may cost much more than the Expense of Salary to an ingenious young Man already well acquainted with both Principles and Practice. This the Irish have learnt at a dear rate in the first Attempt of their great Canal, and now are endeavouring to get Smeaton to come and rectify their Errors. With regard to your Question, whether it is best to make the Schuylkill a part of the Navigation to the back Country, or whether the Difficulty of that River, subject to all the Inconveniences of Floods, Ice, &c., will not be greater than the Expense of Digging, Locks, &c. I can only say that here they look on the constant Practicability of a Navigation, allowing Boats to pass and repass at all Times and Seasons, without Hindrance, to be a Point of the greatest Importance, and therefore they seldom or ever use a River where it can be avoided. Locks in Rivers are subject to many more Accidents than those in still water Canals; and the Carrying away a few Locks by Freshet or Ice, not only creates a great Expense, but interrupts Business for a long time till Repairs are made, which may soon be destroyed again, and thus the Carrying on a Course of Business by such a Navigation be discouraged, as subject to frequent Interruptions. The Toll, too, must be higher to pay for such Repairs. Rivers are ungovernable Things, especially in Hilly Countries. Canals are quiet and very manageable. Therefore they are often carried on here by the Sides of Rivers, only on Ground above the Reach of Floods, no other Use being made of the Rivers than to supply occasionally the waste of water in the Canals.

"I warmly wish Success to every Attempt for Improvement of our dear Country, and am with sincere Esteem,

"Yours most affectionately,

"B. FRANKLIN."

"I congratulate you on the Change of our American Minister. The present has more favourable Disposition towards us than his Predecessor."

"*To S. Rhoads, Esq.*"

hundred years ago (about 1792), was the first turnpike in the United States; whilst the old bridges over the Schuylkill, near Philadelphia (which have given place to the noblest structures of the kind in America), were the first structures erected for the passage of rivers in our country. At the present day, Pennsylvania is unrivalled in the number, the magnitude, and the boldness of design of her bridges.

RAILROADS.

Railroads, also, were first introduced in Pennsylvania. In September, 1809, the first experimental track in the United States was laid out by John Thompson, Esq. (the father of John Edgar Thompson, who was afterward the President of the Pennsylvania Railroad Company), civil engineer, of Delaware county, Pa., and constructed, under his direction, by Sumerville, a Scotch millwright, for Thomas Leiper, of Philadelphia. It was sixty yards (180 feet) in length, and graded an inch and a half to the yard. The gauge was four feet, and the sleepers eight feet apart.

The experiment with a loaded car was so successful that Leiper, in the same year, caused the first practical railroad in the United States to be constructed for the transportation of stone from his quarries, on Crum creek, to his landing on Ridley creek, in Delaware county, Pa., a distance of about one mile. It continued in use for nineteen years. Some of the original foundations, consisting of rock in which holes were drilled and afterwards plugged with wood to receive the spikes for holding the sleepers in place, may be seen to this day.

In 1811, a charter was granted to the Union Canal Company by the Legislature of Pennsylvania, authorizing the company to construct railroads as appendages to that work. On the 31st of March, 1823, a law was passed authorizing Col. John Stevens, Horace Binney, Stephen Girard, and others who have since become distinguished, to construct a railroad from Philadelphia to the Susquehanna. Surveys were promptly executed by the parties named, but they proved to be defective. The delay in obtaining subscriptions for this unprecedented enterprise (*the first of the kind which was ever projected in any part of the world, and the first which was ever authorized by the law in the United States*), induce the friends of this work to apply to the Legislature for certain alterations in the Act of Assembly. On April 7th, 1826, the Act of 1823 was annulled, and a new Act passed authorizing the formation of a new company; and on the 24th of March,

1828, this railroad was made a State work, and is now known as the Pennsylvania Railroad.

In 1816 the first railroad on which self-acting inclined planes were erected was executed by Mr. Boggs on the Kiskeminetas river, in Indiana county.

On the 27th of March, 1824, the Legislature of Pennsylvania passed an Act "providing for the appointment of a board of commissioners for the purpose of promoting the internal improvements of the State." Within four days thereafter, the Governer appointed Jacob Holgate, James Clarke and Charles Treziyulney, who met and effected an organization at Lebanon, on the 16th of April, when they adopted a resolution "to employ an engineer of known talents, skill and experience in canaling, if such an one could be found, and submit to him the organization of such other aid or assistance as he should find necessary."

On May 10th the Board met at Philadelphia, and the President reported "that he had made the most diligent search and anxious inquiry after an engineer who was experienced in constructing canals, and that all his efforts to procure such an one had been unavailing." An attempt was then made to obtain the services of an engineer from the United States corps, but, after some time spent in correspondence, this also failed, and the Board, being left to their own resources, employed surveyors to run levels, and took hold of the work themselves, displaying great energy and perseverance.

After mentioning the fact of having purchased a spirit-level, and ordering four more, the Board in their report proceeded as follows: "When the Commonwealth has the proper instruments, young men will be found who will very soon learn to use them with accuracy and dispatch, and in this way the fruitless effort to get assistance from abroad will be superseded by the culture and encouragement of genius at home. We have found, by observation and experience, that, purchasing the proper instruments, and encouraging active men who have some general acquaintance with science to use them, is the most effectual method for the State to get a proper corps of civil engineers, and to have the most and best work done, in the shortest time and at the least expenses." It is hard to realize at this day that such difficulties in procuring engineers existed at so recent a period; and when we take into view the immense extent of our present railroad and canal systems, we can scarcely believe it to be the growth of fifty years; nor,

when we consider the manner in which engineers were manufactured, should we be surprised that mistakes were made, but rather wonder that so few important errors were committed.

The Mauch Chunk railroad was the third to be finished and put in operation. It was made entirely of wood and worked by gravity. This road commenced at the coal mines which are, in fact, in the valley of the Little Schuylkill, on the Panther Creek, a short distance below the summit of "Mauch Chunk," or "Mountain of Bears." It is used for the purpose of carrying the Schuylkill coal from this valley to the top of the mountain, and thence to the Lehigh river; hence, the common, but erroneous name of this coal, in the market, is Lehigh coal. The road was commenced in the winter of 1826–1827, and was finished in four months. The extent of the main line, which is single, is nine miles, and the branches and side lines extend in the aggregate three and three-quarter miles. This was the first railroad of any considerable extent made in the United States. This road was run with mules, which were walked on the outside of the track to protect the sleepers from wearing; and, the road having considerable descent one way, the cars ran down of themselves. A low car was provided similar to a "gondola" car, and taken with the train; and on that part of the road where the cars ran themselves by gravity, the mules were made to mount the platform of the low car and were *carried down with the load;* and it was astonishing how soon the mules became accustomed to, and fond of this diversion.

On one occasion, the car on which the mules ride down the plane (of about seven miles in length), broke loose, and descended without its passengers (mules), and it became necessary to send for it; the mules, however, with characteristic firmness, refused to be driven down for the purpose of bringing it back. Persuasions, threats, and even the *ultima ratio* of drivers—the logic of the cowskin—could not induce these favored quadrupeds to waive their usual privileges, and to submit to the degrading employment of drawing, in lieu of their pastime of riding, which they had come to look upon as a vested right. Their drivers were actually obliged to change lots with them, and harnessing themselves to the car, to drag it up to the malcontents, who triumphantly took possession of it, and resumed their wonted cheerfulness.

This railroad is better known to fame as the "Switch-back," which has been traveled with such rare gratification by tens of thousands.

From the above, it will be seen that railroads of any description

were first introduced in Pennsylvania; whereas, hitherto, Massachusetts has been given the credit of precedence in this respect.

The fourth railroad was built at Quincy, Massachusetts, by Gridley Bryant, in 1827. This road, which is known as the "Granite railroad," was designed and built by those interested in getting material for the Bunker Hill monument from the granite quarries of Quincy.

The gauge of this road was five feet, and the rails consisted of pine 12 inches deep, covered with oak plank, and protected by flat iron bars. The wooden rails were laid upon granite sleepers 7½ feet long and spaced 8 feet apart. The road had a considerable incline from the quarries towards the landing-place on the Neponset river, and a single horse drew immense loads over the rails. From the wharf the granite blocks were towed around the harbor of Boston by a steam tow-boat and landed at Charlestown. In 1871 this road ceased to exist, being purchased by the Old Colony Railroad.

The Bunker Hill Monument is a granite obelisk 221 feet high, and now marks the scene of the important struggle on Breed's Hill at the beginning of the Revolutionary War. General Lafayette laid the corner-stone, June 17th, 1825, and Daniel Webster delivered one of his most memorable orations on the occasion. The Monument was completed in 1842, and was dedicated June 17, 1843, in presence of John Tyler, President of the United States, and his Cabinet; Daniel Webster being, as before, the orator of the occasion.

## STEAM POWER APPLIED TO RAILROADS.

More than eighty years ago, Oliver Evans, of Philadelphia, discovered the hitherto unsuspected value of railroads, and published to the world that their merits had been unappreciated, their properties misunderstood, and their capacity for extended usefulness undeveloped. He earnestly maintained that they ought not to be confined to limited districts as the mere auxiliaries, or inferior substitutes, to canals; that they were, in fact, greatly superior to the latter for the purposes of general commerce, and on the most extended lines. In these just, and now popular opinions, he stood alone, holding them not the less indubitable because they originated with himself. No human being, at that time, either in Europe or elsewhere, had ever dreamed that railroads were adapted to the transportation of passengers or merchandise, or that they could be usefully extended beyond a length of a few miles.

The idea of employing steam, as a means of propelling carriages, is well

known to be almost coeval with the invention of the steam engine; but no mode of effecting this had ever been tried, or even suggested, unless the mere project of Watt (which, with great deference be it mentioned, is now acknowledged to be utterly impracticable), which was never even attempted, be considered as an exception. Oliver Evans, who had never heard of steam being applied to this purpose, was early impressed with its importance, and commenced his celebrated experiments in 1784, and finished his first engine in 1801. Poverty compelled him to sell it to be used for another purpose. He immediately commenced another engine and carriage, and in the latter part of the winter of 1803–1804 he propelled it by steam through the streets of Philadelphia, in the presence of more than 20,000 astonished and hitherto incredulous spectators, who came with the expectation of seeing a failure.

No railroads then existed in America to test the capacity of this rude but primitive locomotive steam engine. A temporary railway (the first ever attempted in America) was employed to prevent the wheels sinking into the ruts or inequalities, on *part only* of the road traversed. This was the humble origin of that wonderful machine which was destined to revolutionize commercial intercourse by land. The plans and numerous drawings of Mr. Evans were sent to Europe, by his agent, and exhibited to many persons; his suggestions were copied without acknowledgement, and others reaped the benefit of his discoveries.

The superiority of railroads to canals, even when *horses* were employed on both, was zealously maintained by Evans before it had been imagined in Europe or this country, and their greater superiority, when locomotive engines should be adopted, was repeatedly pressed on the public attention. He endeavored, without success, to urge the building of a road from Philadelphia to Pittsburg, and several years after, a railroad from Philadelphia to New York. In the last-named project he offered to take stock to the amount of $25,000, but he was in advance of the age in which he lived. His projects were regarded as visionary, although to-day we are whirled over railroads between the two cities in two hours, and every traveler on them should bear in grateful remembrance the name of Oliver Evans; a man whose projects have been accomplished, and whose predictions have been fulfilled to the letter, although a straight-jacket was voted to him formerly, almost by acclamation, as the reward of his genius. Fitch, who con-

structed the first steamboat at Philadelphia in the year 1787, and Fulton, of Pennsylvania, who successfully introduced steam navigation, likewise had poverty and ingratitude meeded to them as the reward of their exertions.

In the early period of railroad history in the United States, the practice was a lighter construction of the permanent way than was adopted in England. This, no doubt, has materially aided the remarkable extension of railroad lines over so great an area of country. The rails of our early railroads were composed of flat iron bars (strap-rail) attached to wooden string-pieces, 6 x 10 inches, supported on cross-ties similar to those of our present street railroads. The weight of the locomotive, concentrated upon four wheels with a narrow wheel-base, was entirely too much for such a substructure. The roadway soon became uneven, and travel over it was both uncomfortable and dangerous. To the last, the writer can bear testimony. Over thirty years ago he had occasion to make quite a number of trips between New York and Easton, Pa., on the New Jersey Central Railroad (which at that time extended from Elizabethport to Plainfield, New Jersey). Several times on these trips, the end of the rail turned upward and pierced the bottom of the car in close proximity to his person. In railroad parlance these were called "snake heads," and they were often the cause of fatal accidents. On some of the early railroads wooden piles and tressles were first introduced as a substitute both for sleepers and embankments — notably, the South Carolina railroad and the Carbondale and Honsedale (Horatio Allen, chief engineer). The superstructure was composed of flat bars attached to wooden string-pieces (6 x 10 inches), supported generally on piles; the latter were secured by ties. The piles were driven to a great depth in some of the marshes which the road crossed, and in other parts of the work they formed a substitute for embankments.

## STEAM ENGINE.

The production of the steam engine is undoubtedly one of the greatest triumphs of modern science; whether we consider the vastness of its power, so far excelling any mechanical contrivance which, previous to its invention, had been discovered or even thought of; or whether we regard this protean agent with respect to its application to the arts, manufactures or transportation by sea and land. In our own day, through the genius of Watt and Evans, and the inventive talents

of other engineers, the steam engine has become stupendous alike for its force and its flexibility, for its prodigious power as well as for the ease, precision and ductility with which such power can be varied, distributed and applied. Our improved steam engine has increased indefinitely the mass of human comforts and enjoyments, and rendered cheap and accessible, all over the world, the materials of wealth and prosperity. It has armed the feeble hand of man, in short, with a power to which no limits can be assigned, completed the dominion of mind over the most refractory qualities of matter, and laid a sure foundation for all those miracles of mechanical power which are to aid and reward the labors of after generations.

But not one of the uses to which steam power has been applied exceeds, in extent and importance, its application to *locomotion*, connecting, as it does, the most distant points and promoting that facility of intercourse which, of all improvements is the greatest; since, by bringing the different parts of a country together, its strength is increased, and that unity of action and intelligence secured, which brings all, even the most remote and widely scattered districts, into the way of improvement, both moral and mental.

It was an important era in the history of civilization when, about eighty years ago, steam was first applied to navigation. The remarkable facilities which this application afforded to trade and general intercourse, and the great change it has actually effected, and is still effecting, in our commercial and social relations with other countries, are appreciated by all. Previous to this discovery, navigation was impeded, and its utility vastly curtailed, by the uncertain and often opposing action of wind and waves, which often made a voyage of a few miles a matter of toil, uncertainty and delay. Rivers and other great inlets of the sea were of little or no advantage to commerce, and the grand benefits which we generally associate with the very name of *river* were then scarcely known, because no craft could ply constantly on any of the great streams, when they could proceed with certainty in one direction only. As an illustration : In early times on the Mississippi, which flows at the rate of five or six miles an hour, it was the practice of a certain class of boatmen, who brought down the produce of the interior to New Orleans, to break up their boats, sell the timber, and then return home slowly by land ; and a voyage up the river, from New Orleans to Pittsburgh, a distance of about 2,000 miles, could hardly be accomplished, with the most laborious efforts,

within a period of four months. Now the above journey is easily performed in about three days.

LOCOMOTIVES.

During the summer of 1829, a small experimental locomotive, built by Peter Cooper, of New York, was successfully tried on the Baltimore and Ohio Railroad, at Baltimore, making 13 miles in less than an hour, and moving, at some points on the road, at the rate of 18 miles an hour. One carriage, carrying 36 passengers, was attached. This was considered a working model; but, what was most important, he demonstrated that it could run at a high rate of speed round curves of a short radius.

Mr. Cooper made the above experiment at the *same time* that Robert Stephenson's locomotive, the "Rocket," was run on the Manchester and Liverpool Railway, in England.

Ross Winans, writing of the trial of the Cooper locomotive, makes a comparison with the work done by Stephenson's "Rocket," and claims a decided superiority for the former. He concluded that the trial established fully the practicability of using locomotives on the Baltimore and Ohio road at high speeds, and on all its curves and use gun barrels. The whole machine weighed less than a ton.

It is a rather curious coincidence that both Oliver Evans and Peter Cooper were coach-builders or wheelwrights by trade.

The fact is, that applying the steam engine to locomotion with heavy gradients without inconvenience or danger.

To show the disadvantage Mr. Cooper labored under, he was unable as to find such tubes as he needed for his boiler, and was compel regarded as a much smaller mechanical feat in America than it was in England. The representative steam engine in Britain, at the time railways were first started, was the heavy, slow-moving condensing engine of Watt. Radical changes were necessary to convert that engine into a locomotive. America, on the other hand, had the high-pressure, high-speed engine, invented by Oliver Evans, and it was well adapted for land transportation purposes without change of type.

While the directors of the Liverpool and Manchester Railway, in England, were disputing about what system of operation to adopt, the majority favoring stationary engines and rope traction, the directors of the Baltimore and Ohio and the Charleston and Hamburg Railroad, of

South Carolina, unanimously decided to operate their railroads with locomotives, and gave their general managers directions to have locomotives built.

The Gartner & Davis locomotives, that did the first regular service on the Baltimore and Ohio Railroad, were constructed after the style of the Cooper locomotive.

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## On the THEORY of the FINANCE of LUBRICATION, And on the VALUATION of LUBRICANTS by CONSUMERS.*

By Robert H. Thurston, Hoboken, N. J.

(Concluded from page 45.)

The variation of friction with pressure, above alluded to, is illustrated by the following values of the coefficient of friction, as obtained by the writer, the journal being of steel, in good order, the bearing of bronze—gun metal—working at a speed of rubbing of 150 feet per minute, and running barely warm to the hand, conditions common in practice.

*Friction at Varying Pressures.*

| Oils. | Pressure: lbs. per sq. inch; kgs. per sq. cm. | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 4<br>0·3 | 10<br>0·7 | 25<br>1·8 | 150<br>10·5 | 200<br>14·1 | 250<br>17·5 | 300<br>21·1 | 500<br>35·2 |
| Sperm | 0·12 | 0·08 | 0·04 | 0·01 | 0·01 | 0·01 | 0·005 | 0·003 |
| Lard | ........ | ........ | 0·06 | 0·014 | 0·013 | 0·011 | 0·006 | 0·004 |
| W. Va. | ........ | ........ | ........ | 0·012 | 0·009 | 0·008 | 0·005 | ........ |
| Grease | ........ | ........ | ........ | 0·025 | 0·020 | 0·015 | 0·012 | 0·011 |

The journal was lubricated, in the usual way, by means of an oil cup, the oil feeding down by a wick. As the cup was kept full, the supply was very free, and the figures are probably good for the case taken. These figures may be doubled by the selection of an unguent ill adapted to the work, and may be increased to almost any extent by abrasion and cutting. On the other hand, they may be decreased at least one half by freer supply.

The amount of lubricating materials used in cotton mills has been investigated by Mr. Edward Atkinson, who finds that, in fifty-five mills, working on similar fabrics, and among which a variation of 20 per cent. should not have been expected, the actual range was 350 per per cent. Subsequently, careful management reduced the average from \$10.03 to \$6.67 per 10,000 pounds of cloth made. Another and still more important effect of this investigation, and the publication of its results, was the expulsion from that market of inferior and dangerous oils. The oils found in use, and tested, varied in quality to the extent of 300 per cent. The best oils for these mills were reported by Mr. Woodbury as being mineral oils mixed with some sperm or lard, and having a gravity of about 28 to 32 Beaumé (S. G. 0·886 to 0·864).*

The total power used in these mills is found by Mr. Henthorn to average about 0·75 horse-power per loom, or 15·75 horse-power per 1,000 spindles, and to vary from 0·5 to nearly one horse-power per loom, or from 11 to 22 horse-power per 1,000 spindles. The same authority finds the power demanded by engine and shafting alone to form from 17 to 34 per cent. of the whole. The smaller of these figures represents the best practice, the higher figures show what may be expected with faulty arrangement and bad lubrication. The quantity of cloth made in New England mills, according to data furnished the writer, mainly through Messrs. Hoadley and Woodbury, ranges from about 2,000 pounds per annum, per horse-power, up to above 3,500. A variation of temperature, such as occurs between winter and summer, causes a variation of ten per cent. in the production of cloth, the greater amount being obtained in summer. A mill making print, cloths, 64 threads to the inch, and of No. 32 yarn, with frame warp and mule filling, produces about one pound of cloth per spindle per week, and demands about 16 horse-power per 1,000 spindles. Thus 10,000 pounds of cloth per annum requires 200 spindles, and proportional plant, costing about, at present prices, or a little above, \$11 per spindle for all machinery and buildings, exclusive of stock, land, and live capital, and the power demanded is not far from 3·3 horse-power. A New England mill, well known to the writer, contains 44,752 spindles, makes 7,800,000 yards of cloth per year, weighing 1,240,000 pounds, the mill running 3,000 hours per annum, using 625 horse-power, and consuming 700 gallons of sperm and 2,900 gallons of min-

* Transactions of the American Soc. Mech. Engineers, vol. iv, p. 319.

eral spindle oil per year. The sperm oil cost, at last reports, $1.22 per gallon, and the spindle oil 25 cents. Another large mill, near Boston, working 55,000 spindles, makes, annually, about 3,000,000 pounds of cloth, requiring 1,300 horse-power, and using oil costing $1,300 per year. A 37-set woolen mill makes 750,000 pounds of cloth and uses 300 horse-power.

On the whole, it may be said that the quantity of oil used in cotton mills varies from 10 to 30 gallons per 10,000 pounds of cloth made per annum, averaging not far from two gallons per horse-power per annum, and costing from 20 cents to $1 per gallon, averaging probably not far from 50 cents.

A machine shop uses, properly, a much heavier oil than a cotton mill, and much less in proportion to power employed. One of the largest and best-known steam engine building establishments in the country uses 120 horse-power, and consumes 350 gallons of sperm oil for the heaviest machinery, such as planers, and for the wood-working tools, 100 gallons of finest heavy mineral engine oil for the engine, 300 gallons of mineral or mixed oil, at about 40 cents per gallon, for shafting and tools, and expends a total, on lubrication, of about $600 per year, an average of about 80 cents per gallon. Another and smaller shop, also well known to the writer, employs but 30 horse-power, and uses 175 gallons of oil per year for lubrication, the average cost being but 18 cents per gallon. Still another establishment, building tools and light machinery, uses an estimated amount of 100 horse-power and 700 gallons of oil at 20 cents per gallon, and for grease used on the main line of shafting, 25 cents per pound. A similar shop of somewhat larger size, reports to the writer an expenditure of but 40 gallons per year on 550 bearings, the oil being supplied by hand, a certain number of drops at a time, at regular intervals. Probably a fair estimate for the heavy class of machinery found in such establisments may be about 0·0002 gallons per horse-power per hour.

The Lowell Pumping Engine, designed by Mr. Leavitt, uses about 0·00015 gallons per horse-power per hour, a very low consumption for that class of machinery.

Railway work is probably more exacting in its demands, and more variable in its practice, in regard to quantity of oil used, than any other class of machinery consuming lubricants. Its character is such that it should be comparatively easy to select the best lubricant for the case; and yet there is probably no class of machinery on which a wider range

of quality and price of oil is to be found in use. The trade in oils for this work is in a singularly unsatisfactory state; and no system is generally practiced by which to determine precisely which oils are best for the purpose. Consequently, the losses due to mistakes in selection, and in the use, of oils are often of enormous magnitude. In no direction is a definite method of test, purchase, and use of lubricants more desirable than in this.

The consumption of oil is usually reckoned per train-mile, and the following are the figures given by one of the best of the Massachusetts roads for one month on the engines alone:

| | Coal—Lbs. per mile. | Oil—Gallons. |
|---|---|---|
| Best Express Engines | 43 | 0·009 |
| Best Freight Engines | 55 | 0·0094 |
| Average Passenger Engines | 50 | 0·009 |
| Average Freight Engines | 61 | 0·0084 |

The Boston and Albany Railroad, in November, 1884, reported the following:

| | |
|---|---|
| Cost of fuel per mile | $0·179 |
| Cost of lubricants per mile | ·0052 |
| Cost of repairs per mile | ·0441 |
| Total | $0·2283 |
| Miles run per ton of coal | 39·18 |
| Miles per quart of oil | 28·93 |

On the Boston and Maine road, the cost of fuel is given at about ten cents per train-mile, that of oil about one-half cent. The average of all Massachusetts roads in one year, as given to the writer, was for wages on the engine, $0·28, for fuel, $0·115, and for oil and waste, $0·0105. On the Pennsylvania Railway, between New York and Pittsburg, in 1883, the totals were reported as follows:

| | |
|---|---|
| Total mileage | 15,625,478 |
| Coal, tons of 2,000 lbs | 743,020 |
| Wood, cords | 13,685 |
| Oil, quarts | 613,478 |
| Tallow, lbs | 721,992 |
| Waste, lbs | 267,158 |
| Tons moved one mile | 2,996,893 |

The coal averaged in price but $1.00 per ton, exclusive of freight

charges to the road, the wood cost $2.88 per cord, the oil 28 cents per gallon, the tallow and waste, each 8 cents per pound.

The New York, Lake Erie and Western Railway reports for December, 1884, as follows:

*Performance of Locomotives.*

AVERAGE, MONTH OF DECEMBER, 1884.

Length of Road......................................................563 Miles.
Total No. Locomotives, 241. No. making Mileage, 205.
Miles run per Locomotive..........................................2474·30
No. of Cars per Trip—Passenger 5·0, Loaded Freight...... 18·9
Percentage of Empty Freight Cars of all hauled............ 14·4
5 Empty Freight Cars rated at 3 Loaded.

MILES RUN TO

1 Ton of Coal by Locomotives 20·46, by Cars hauled........ 332·21
1 Pt. Lub. Oil and T. by Locomotives 13·55 " ........ 179·90
Lbs. Waste used per 100 miles........................................ 0·32

COST, ETC., PER MILE.

| | | Loco. Mile. | Car Mile. |
|---|---|---|---|
| Fuel used | pds. | 95·36 | 7·19 |
| Cost of Fuel | cts. | 6·16 | 0·47 |
| " Oil, Tallow and Waste | " | 0·52 | 0·03 |
| " Repairs | " | 4·02 | 0·26 |
| " Loco. Furniture and Fixtures | " | 0·13 | 0·01 |
| " Wages Engineman and Fireman | " | 6·34 | 0·39 |
| " Repairers and Cleaners | " | 1·01 | 0·06 |
| Total Cost | | 18·18 | 1·22 |

Cost of Wood per Cord, $2.74. Coal per ton, $1.25.
Time table mileage allowed and 5 m. per hour for Terminal Switch.

COST PER MILE, ETC., FOR

Repairs of Passenger Cars, 0·53 cts. Repair of Freight Cars, 0·25 cts.
Lub. Oil, Pass. Train Cars, 0·06 " Freight Train Cars, 0·01 "
Miles per Pt. " " 56·56 " " 210·32 "

The cost of wear of journals and of bearings does not appear, as a separate item, in the preceding statistics of railway economy; but, as already stated, it is often a very serious expense. It has been found that, in some instances, the average wear is about one pound of journal for each 75,000 miles run, and the same weight of bearing for each 25,000 miles. Could the lubrication be made as perfect and the dust be excluded as thoroughly as in indoor work, the wear would be reduced

to a fraction of one per cent. of these amounts, and would become insignificant. In one case reported to the writer, it was found that the cost of oil, for 100 cars moved 100 miles, was about \$1.00, that of power \$8.00, and the expense for wear of journals and bearing was \$5.00 nearly. The estimate for cost of power is perhaps rather low. This remarkable case was observed where the lubricant was "black oil." The tendency of this oil to produce injury of surfaces was called to the attention of the writer, some years ago, by a well-known railroad superintendent, who sent him samples of staybolt-rods whose threads had been cut, one with lard, and the other with black, oil. The first was as smooth as could be desired; the second was rough, ragged on the edges of the thread, and in places the thread was completely stripped. No difference had been made in cutting except in the choice of the oils.

The cost of steam-power, which is usually the principal item included in the cost of the wasted work of friction, varies greatly with size and kind of engine, character of fuel, expenses of operation, and with all the items, such as insurance, repairs and depreciation, incidental to its use. A fair figure is, perhaps, for ordinary mill-engines of moderate power, \$0.02 per horse-power per hour, and double this amount is not unusual. Of this total, from 50 to 80 per cent. may be assumed to be, on the average, the cost of fuel. Adding the incidental costs, it may be considered a fair estimate, for such cases, to take the total charge at \$0.03 per horse-power and per hour. As the values of all items of expense, in every case, in practice, will be determined by direct experiment* and by observation, it is unnecessary to enter into this division of the subject very minutely, when, as here, only illustration of the principles developed is proposed.

The actual cost of steam-power in mills ranges from as low as \$50 to as high as \$100 per horse-power, according to circumstances. The latter figure represents the cost of the best modern machinery. The interest on first cost may be assumed at 6 per cent., the appropriation for a sinking fund at 2½ per cent., the working expenses at not far from 10 per cent., in good cases, and the cost for fuel, on the average, at about 20 per cent. of the cost of the plant. The total cost, thus calculated, will vary from, perhaps, \$35 to nearly, or quite, \$100 per annum, per horse-power. It has been taken, above, at \$60, and about

* "On the several Efficiencies of the Steam Engine," Trans. Am. Soc. Mech. Engrs., Vol. III, p. 245, Journal of the Franklin Institute, May, 1882, Art. XIII.

fifty per cent. of its own amount added for miscellaneous costs not included in the direct calculation.*

In illustration of the application of these principles, the following cases, which are examples of practice falling within the experience of the writer, may be given:

(1.) In a machine-shop using about 100 horse-power, of which one-half is supposed to be applied to the overcoming of the friction of lubricated surfaces of journals and their bearings, it is found that the cost of power is very nearly $100 per horse-power per annum, inclusive of all of the incidentals above mentioned. The average coefficient of friction is not far from 0·05; the oil used costs, on the average, $0.50 per gallon, consisting mainly of lard, and heavy mineral oils, and is supplied at the rate of 0·02 gallons per working hour, the working year consisting of 3,000 hours.

Then, if 50 horse-power should be used in the work of overcoming fractional resistances, the cost of power would be $5,000 per annum, or $1.67 per hour, which is represented, in the equations already given, by $b\ f_1$. Since $f_1$ is found to be 0·05 $b$ is equal to 33·333. The oil used being found to cost, in place on the journal, $0.50 per gallon, and to be used at the rate of 0·02 gallon per hour, the total cost of lubrication is $0.01 per hour. Hence we have (Eq. 4):

$$K_1 = k_1 q_1 + b\ f_1 = 0{\cdot}01 + 1{\cdot}67 = \$1.68 \qquad \text{(A)}$$

or $5,040 per annum.

Should it be proposed to make a change of oil, using oil costing but $0.25 per gallon, and of which 0·03 gallon per hour will be demanded, and which will make the coefficient of friction 0·06, the cost of power will be increased one-fifth, and that of oil diminished one-fourth; the equation then reads:

$$K_2 = 0{\cdot}25 \times 0{\cdot}03 + 33{\cdot}333 \times 0{\cdot}06 = \$2{\cdot}0075 \qquad \text{(B)}$$

equal to $6,022 per annum.

The gain effected in cost of oil is one-fourth of one cent per hour; while the loss, in cost of wasted power, is 33·333 cents per hour. In other words, a gain of $7.50 per annum on the books of the purchasing agent, or proprietor, is to be charged against a loss, in the cost of

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† For details of such estimates, see the papers and reports of Messrs. J. C. Hoadley and C. E. Emery, especially on the Watuppa Reservoir Case, and estimates presented to the American Society of Civil Engineers.

running the establishment, of \$1,000. The net loss is \$982.50 per annum.

Should it prove possible to adopt a system of oil-baths, or other method of free lubrication, so as to bring down the coefficient to 0·02, as is not at all unlikely to prove practicable, and assuming that four times as much oil, of the second quality, is used as in the last case, we shall have

$$K_2' = 0{\cdot}03 + 0{\cdot}666 = \$0.696 \text{ per hour,} \qquad \text{(C)}$$

\$2·088 per year, producing a gain of two-thirds the total cost of lost work, as in the last case. This amounts to nearly \$4,000 per year, or, as compared with the present running expense, as given in the first case, to nearly \$3,000. The annual cost of oil, in the three cases, amounts to \$30, \$22.50 and \$90, respectively, and it is at once seen that, in this example of application, the saving, actual or possible, to be effected by any bargain made in the oil market, is absolutely insignificant in comparison with that to be produced in the shop by careful lubrication. A system of collection and purification of the oil running off the journals into the drip-pans may, in nearly all cases, be easily adopted, which will at once reduce the cost of lubricant, and make its first cost a matter of still less consequence.

Finally, suppose a grease used in this shop, such as now costs 25 cents per pound, and assume that it is given as a sample, costing the proprietor nothing, but bringing up the coefficient of friction, as an average, to 0·10: The cost of power is now the total expense, and this becomes

$$\$3.333 \text{ per hour,} \qquad \text{(D)}$$

or \$10,000 per annum; while the loss to the owners of the establishment, on their bargain, is \$5,000 per annum.

It will next be asked: What price represents the limit which may not be exceeded, without loss, in the purchase of the oils proposed to be substituted for that first used in this instance? This question is answered by the application of the criterion established by equations (10) and (14). Thus, comparing cases (A) and (B), we have

$$k_2 = \frac{k_1 q_1 - b(f_2 - f_1)}{q_2} = \frac{0{\cdot}01 - 0.333}{0{\cdot}03} = -\$10.78.$$

The second oil causes a loss of \$10.78 for every gallon used, and, hence, cannot be used without loss, unless the user is paid that sum to take it and apply it to his machinery.

Comparing cases (A) and (C), using equation (10),

$$k_2 = \frac{0 \cdot 01 + 1 \cdot 00}{1 \cdot 2} = \$0.84\,;$$

and it is found that the second disposition of the poorer grade of oil is of such advantage that it is as well worth \$0.84 per gallon as is the better oil worth \$0.50, used as at first proposed, and as is customary. But it would be a still better investment, in all probability to purchase the better oil, and to use as in the case compared.

Comparing cases (A) and (D), using equal amounts, per gallon,

$$k_2 = \frac{0 \cdot 00 - 33 \cdot 333 \times 0 \cdot 05}{0 \cdot 02} = - \$83.44\,;$$

and the heavier lubricant is found to subject the user to an expense amounting to over \$10 for each pound used. It must not, however, be from this inferred that it is always wasteful to use the greases. They are often advantageous, where exceptional pressures are used or troublesome bearings are met with, and are sometimes absolutely indispensable, saving large amounts by their reduction of expenses in the cooling and preservation of journals and renewal of bearings. In the above case, it is probable that a much smaller quantity of grease than of oil would have sufficed, which would have reduced the total cost of grease, if purchased, but would have proportionally increased the loss to the proprietor, both absolutely and as reckoned per pound of unguent applied.

(2). As a second illustration, assume a cotton mill to use a good oil, averaging \$0.70 per gallon, at the rate of 0·7 gallon per hour, with a mean coefficient of friction 0·10 on machinery demanding 400 horse-power, of which 120 horse-power is required to overcome the friction of surfaces lubricated by the oil. Taking the value of the power at \$65 per horse-power per annum, and 3,000 working hours, we have $b = \$26$. If it is proposed to substitute for the oils used in this mill others averaging a cost of \$0.40 per gallon, giving a mean coefficient of friction of $f = 0 \cdot 12$, and of which one gallon will be used per hour, we shall have

$$K_1 = 0 \cdot 49 + 2 \cdot 60 = \$3.09,$$
$$K_2 = 0 \cdot 40 + 3 \cdot 12 = \$3.52,$$

and a gain of 9 cents per hour, or \$270 per annum, in buying oil, is to be set against a loss of 52 cents per hour, or \$1,560 per year, in

increased expenses on the account of operating the mill, the net loss amounting to above one thousand dollars a year. Had the coefficient of friction been increased to a greater extent, the loss would have been correspondingly greater. The differences among the lubricants sold for mill purposes in the market are sometimes enormously greater than assumed above, and a loss of \$10 per horse-power, annually, is probably not an unknown case, and this is equivalent to about double that sum per horse-power expended on the friction simply.

Applying the criterion to this case, we have

$$k_2 = \frac{0{\cdot}49 - 0{\cdot}52}{1{\cdot}0} = -\$0.03,$$

as the loss on each gallon of the second lubricant. The owner of the mill cannot afford to accept it, in substitution for the better oil, as a gift. The substitution of an engine-oil, on the spindles, for the best spindle-oil, might readily double the expenditure of power absorbed by the spinning machinery, and thus increase the cost of both lubrication and power, the former having both a higher co-efficient of friction and greater price than the latter.

(3.) In further illustration, assume a railway train to be supplied with a good standard lubricating oil for engines and axles, costing, on the journal, \$0·25 per gallon, and to use 0·02 gallon per train-mile, the co-efficient of friction, when everything is in good order and all journals cool, being 0·01. Taking as a fair figure, \$0·10 per mile for costs of power and incidentals variable with power, and presuming that, under the circumstances, wear may be reduced to an unimportant amount, and may be neglected, the relative costs of lubricating material and of power may be introduced into equations (18) and (19), as in the above examples. We thus obtain

$$K_1 = k_1 q_1 + df_1 = 0{\cdot}005 + 0{\cdot}10 = \$0{\cdot}10\tfrac{1}{2},$$

as the total money-loss due to the existence of friction.

If it be proposed to substitute for the oil in use a cheaper oil, costing, on the journal, \$0·15, and of which fifty per cent. more will be used, and which will give a coefficient of friction 0·015—a not uncommon case—the total cost becomes

$$K_2 = 0{\cdot}15 \times 0{\cdot}03 + 10 \times 0{\cdot}015 = \$0{\cdot}15\tfrac{1}{2};$$

and it is found that a gain of one-twentieth of a cent, per mile, in cost of oil, is met by a loss of one hundred times as much, or five cents

per mile, in cost of power. Should the second oil increase wear, its cost must be added to the account of losses produced by the change. Had the second oil been used in the same quantity as the first, one and a half cents per mile would have been saved, over the last figures, and the loss would be then $3\frac{1}{2}$ cents per mile.

To determine what could be paid for the second oil, as used, in order that no loss should take place in consequence of the change, equation (17) is to be used, and this gives

$$k_2 = \frac{0{\cdot}005 - 10 \times 0{\cdot}0005}{0{\cdot}03} = \$0{\cdot}00\,;$$

that is to say, the real value of the oil to the consumer is just 0, if the oil at first used was worth 25 cents a gallon. In many instances, in every-day practice, losses occur many times as great as those just estimated.

The conclusions to be drawn from the principles and the theory which have been presented in this paper, and from the examples of application to practice which have been introduced as fairly representing their use in various departments of engineering, are obvius and definite:

(1.) To secure the highest possible efficiency of machinery, and maximum economy in the operation of establishments in which it is employed, lubricants must be very carefully selected with reference to the precise conditions, as to pressure, velocity of rubbing, etc., met with in the individual case.

Where, as in machine-shops and mills, for example, there exist great differences in these respects, it will be found advantageous to use different oils; as heavy oils on the engine-bearings, special "cylinder oils" in the steam cylinder, lighter oils on the shafting, and the lightest of the better classes of lubricating oils on light machinery, as on spindles.

(2.) Differences in price of oils, or other lubricants, are usually of exceedingly slight importance in comparison with differences in costs of power; and the value of the coefficient of friction is, therefore, of vastly greater consequence than either the price of the unguent or its endurance.

(3.) The best oils for specified purposes should be taken, as a rule, whatever their market price; while the oils which are not well adapted to the purpose in view cannot be economically purchased at any price.

It will often be found that the best quality of oil is not necessarily the best oil for any one specified purpose. An oil may be intrinsically excellent, and may be a very expensive oil, but may, nevertheless, be absolutely worthless for the purpose in view. A good engine-oil would, for example, be quite unfitted for use as a spindle-oil, and, though several times as high in price, might be the cause of such considerable waste of power on light mill-machinery that the mill-owner, as has already been seen, might find it to his interest to decline using it, even if it were offered him as a gift. The heavy oils are the most costly, and, in this case, the better oil is, therefore, also the cheaper in the market.

(4.) The cost of using a lubricant which is not well adapted to the work is so great that unguents should always be tested, and their adaptability to the special case determined, by a correct system of chemical and physical tests, and by trial upon a good testing-machine, if possible, under the exact conditions of the intended use.

The determination of the quality of any lubricant is an easy task; but the identification of the real conditions of use, as proposed, may sometimes be difficult. The difficulty arises, however, not from faults of method of test or uncertainty of results, but from defects of design or construction, or sometimes of management, of the machinery upon which it is proposed to use the oil. Where journals are kept in good order, and are properly proportioned, no difficulty need ever arise in the attempt to find the best possible lubricant for them. As a rule, there is no excuse for a condition of machinery which gives rise to such uncertainties. As a rule, in all successfully conducted departments of business, such uncertainties do not exist; they do not arise with sufficient frequency to invalidate the above rules. Testing-machines are now made in sufficient variety of form and of ample range of application, and of such satisfactory accuracy, that there is no longer necessity of accepting the risks, and of meeting the enormous expense, involved in the application of lubricants of unknown quality to valuable machinery.

(5.) Where lubricants of the precise quality desired are not found in the market, it is advisable to secure the right grade by mixing. This can always be done by making a series of mixtures of good oils, such that, at the one side, the gravity and other qualities shall be too high, and, on the other side, too low, for the special application had in view, and thus working out—after determining by trial the law of

variation—the mixture most perfectly suited to the purpose. The writer has often been called upon thus to determine the best of a series of mixtures for a cylinder-oil, for example, or for an engine or a spindle-oil. By this method he has sometimes improved the quality of an oil for a special kind of work more than one hundred per cent. Satisfactory results can almost invariably be attained by careful and skillful work.

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## CRYSTALLIZATION.*

By Dr. Persifor Frazer.

Ladies and Gentlemen:—We find in nature two classes of phenomena: changes in the act of taking place, and actual existences which are the results of changes which have taken place; or, to speak more accurately, changes proceeding so rapidly that we can note them, and others so slowly that they seem to us to be states of equilibrium. It is rarely, if ever, that phenomena are due to one cause unmodified by others. When not the outcome of the operation of a single cause, the phenomenon in question is a resultant analogous to that explained in mechanics by the diagram of forces, and as such may be made to show the relative force of each cause. Such resultant phenomena are least frequently produced by few and nearly equal causes, and when so, they evince this by their simplicity whether geometrical or other. More frequently they are the effects of many unequal and unlike causes and constitute objects which all the efforts of science thus far have not sufficed to unravel completely.

Among the phenomena of which the creating forces have been comparatively few and like, are those curious and beautiful objects known as crystals, to which it is intended to devote your attention this evening.

It has been said that when the forces acting simultaneously upon a body were comparatively few and similar, the resultant forces were usually simple. Observe the lines of the figure made when a mass of fragments is piled up and allowed to find that state of rest which results from the combined gravitation of the earth and the resistance

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* A Lecture delivered at the International Electrical Exhibition, Tuesday, October 7, 1884.

of the particles to compression. One sees these lines in the dump piles of our great ore mines and furnaces, in the piles of debris which crumble and fall from vertical cliffs; and indeed in every grocer's shop when sugar or coffee is scooped from the bins and piled on the scales. The attraction of gravitation tends to carry all the particles straight to the centre of the earth, but there being the resistance of the matter which interposes, the particles jostle each other and fall sideways in all directions. [*Illustrations of talus were projected on the screen.*]

The same kind of phenomenon, but from different causes, is seen in stalactites. Here the drop of liquid tends to fall, but the attraction of cohesion constantly increasing through the evaporation of the solution and the consequent crowding together of the solid substance which it contains, the drop is arrested in its path; and finally the cohesive force triumphs and the stalactite is made by so much the larger. The manner in which this building takes place can be seen by observing any stalactite.

Sometimes these same forces applied differently give rise to a different result, as for instance, in the mineral springs, which in overflowing at the surface, evaporate and leave incrustations which build up circular walls unlike those of the stalactite or stalagmite. The forms which these openings assume are dependent upon the strength of the solution, the nature of the salt, the force of the spring, and the rapidity of evaporation; and all of these are factors in the resulting form, though all functions of the same simple pair of causes. [*A photograph of one of the Yellowstone Geysers was projected on the screen.*]

Symmetrical form is not only produced by building, but also by destroying; and analogously to the art which hews out of the block of marble the beautiful statue, so the forces of nature; the wind, the frost and the rain, with the aid of gravitation, chisel out of solid sandstone beds forms of symmetry often of great beauty, as for instance, in the "Garden of the Gods," in Colorado, and elsewhere. [*Photographs of various forms of which were thrown on the screen.*]

Other symmetrical forms, oftentimes closely resembling crystals, are formed by the rapidly cooling lavas or molten streams which force their way upward to the earth's surface when in the act of congelation the constituent molecules seeking room for themselves press their fellows in all directions and in turn are pressed by them. The columns thus formed are quite uniformly five-sided. [*Projections of the Basalt, of the Giant's Causeway.*]

The above symmetrical forms are the results of various simple forces acting simultaneously on matter, but none of them are forms of crystallization as usually understood; and a better definition of this latter is now necessary.

It will be observed that the above forms have been impressed upon the passive matter which exhibits them, by extraneous forces. The matter has merely been the plastic material to receive impressions from outside forces correlated to its essential character. But in crystallization the case is reversed. The matter assumes form from a centre or centres *within* its own mass in all directions *through* its own mass. By virtue of what power?

The answer to this question is virtually my reason for appearing before you this evening, for the managers of this lecture course have very wisely requested their lecturers to confine themselves as much as possible to subjects germane to the Exhibition which is now proceeding here; that is, of Electricity in some of its forms of manifestation, and one of these forms has been long known to be magnetism. The force which impels the minute particles of a crystallizing body to so arrange themselves, the one upon the other, that a symmetrical form results, has been finally traced by the master scouts in the army of original investigators in Nature's domain, to intimate connection (if not identity) with that mysterious attraction of the loadstone for iron; and this attraction will here properly become the subject of a short consideration

[*A magnetic needle was here projected on the screen by means of the vertical lantern.*]

This familiar instrument needs no explanation to this audience so far as regards its simpler manifestations (though, did time permit, many wonderful things about it and the manner of its action might be profitably said).* In my hand I hold a thin slab of steel in the condition of a magnet, and you observe that one end attracts, and the other repels a given end of the needle while the middle of the bar acts indifferently towards it. If the bar be broken at this point of indifference the two ends thus formed instantly change their action. Instead of indifference one end strongly attracts and the other as strongly repels a given end of the needle, while the opposite extremities of the fragments to which these ends respectively belong have the opposite action. But now the middle

* It is hardly necessary to explain to the readers of these lines that this manner of presenting the subject was first adopted by Prof Tyndall.

point of each of these fragments is indifferent. Breaking each of them again the same apparently marvelous accession of energy is noticeable, and so on as far as mechanical means permit us to sub-divide matter. Each of the minutest fragments exhibits the same qualities just observed in the larger pieces, *i. e.*, with reference to a given pole of a magnetic needle attraction at one end, repulsion at the other end and indifference in the portion—first called by Faraday in a sort of grave scientific pun—the "equatorial zone." Note, however, the following facts. So long as the magnetic force exercised by every particle on its neighbor is approximately equal to that exercised by either end of the large unbroken bar, the effect of sub-division is not merely to separate but to increase the polar force relatively to the equatorial indifference. For, when the bar is broken in two, each of the halves will divide into fragments of two poles and one equator midway between them. The result of successive divisions will be to continually diminish the zone of indifference relatively to the regions of magnetic force, and the effect of this, in a state of extreme comminution, as if the middle zone of these minute magnets disappeared and left simply the attraction and repulsion of their opposite extremities. This is an important aid to understanding the final arrangement of these little particles by their mutual attractions and repulsions.

This will be illustrated to you in a moment, but before thus making the experiment let us recapitulate that: by every subdivision of the parent magnet (following our experiment), the polar activities are increased in the proportion of 2 in the original bar, 4 after the first break, 8 after the second, 16 after the third, and so on: whereas the number of different zones is increased only from 1 in the original to 2 after the first break, 4 after the second, and 8 after the third, etc.

Thus the number of seats of action and the activity of action, as the masses grow smaller, increase; while the seats of neutral or balanced activity become narrower. These facts are also important to bear in mind when one seeks to understand the marvelous rapidity and immense force manifested by the phenomena which are the subjects of this lecture.

It will be shown that the one pole of the same bar seems to repel poles like itself of other bars and to attract those different from itself. What then would be the effect if a large number of little magnets were scattered between two large ones?

[*Iron filings were here sifted upon a plate of glass resting on the condenser of the vertical lantern, and this covered by a second plate. The north ends of two bar magnets were then placed on the second plate. Afterwards the opposite poles of the bar magnets were substituted.*]

In both of these series of curves the direction is due first to the paramount attraction of the large centres for each particle of the iron filings as a whole; and second to the repulsion from each other of similar parts in the adjacent little magnetized particles, which are, each, a little magnet.

The great Faraday pondered these lines of force deeply and started a series of investigations which are not yet complete but which have already led to interesting results.

Brugmans, Le Bailliff, Seebeck and Becquerel had already been at work on the subject before 1846. Weber, Œrsted, Reich, Plücker, Tyndall and Knoblauch, all contributed largely to the research, but the results, important as they are, cannot be considered here except as to one particular.

Faraday had divided all bodies examined by him into paramagnetic and diamagnetic, *i. e.*, those which arranged themselves (1) in a line joining the opposite poles of a strong magnet, or (2) in a line perpendicular to this. Of the first class iron was the type; of the second, bismuth. So far as these results apply to crystals they must now be prefaced by a few words on the structure of these beautiful bodies. [*Combinations of prisms and pyramids thrown on the screen.*]

For the sake of convenience, all crystals have been divided into forms belonging to seven systems, called crystallographic systems, but these seven systems are not necessary for the mathematical study of the phenomenon, although they render the study easier of classification.

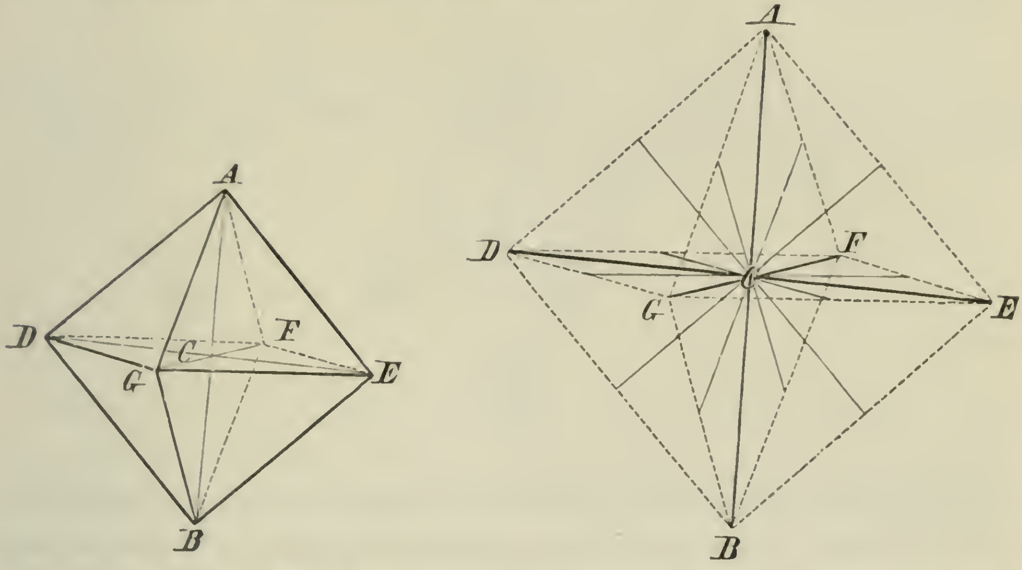
For the sake of simplicity, the *central point* of a crystal (an arbitrary point, only definable in crystals or solids which are symmetrical) is assumed as the point where certain arbitrarily chosen straight lines intersect. Usually these straight lines or co-ordinate *axes* are restricted to three, but in one case (again for a mere convenience) they are increased to four. With this explanation, they may be rapidly sketched.

The seven crystal systems are divided into the orthometric systems, or those in which the axes make, with each other, only right angles, and the klinometric systems where they make one or more oblique angles.

Those portions of the "main axes" which are wholly enclosed within the crystals are called parameters, and the shape of the whole

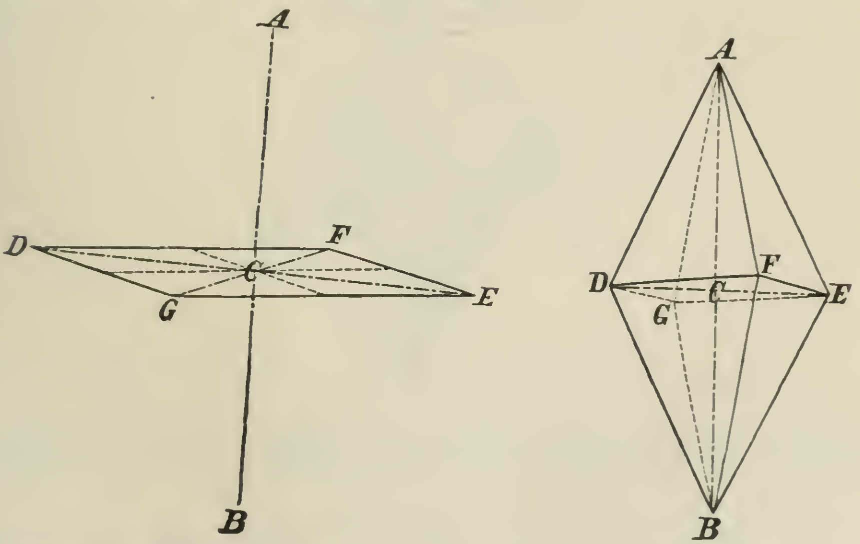
crystal is determined by the relative lengths of the parameters—the latter being the distance from the centre of the crystal along every axis to the intersection of that axis with some part of the surface of the crystal.

The first of the systems is the *Isometric,* in which the three axes are equal and perpendicular each to each.




[The lines *A B*, *D E*, and *F G*, are the three principal axes ; the first or the *main* axis is always supposed vertical, and the others are the *subordinate* axes.]

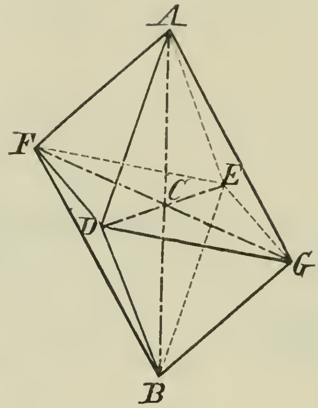
The next is the *Tetragonal,* of which the parameters are perpendicular each to the other. But two of them are equal in length, and these two longer or shorter than the third.




[The letters in this and the succeeding diagrams correspond with the analogous points in that of the isometric pyramid.]

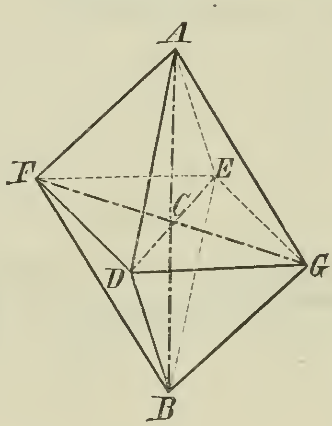
In the *Rhombic* system, all three axes are perpendicular each to each, but no two of them are of the same length. These constitute all the orthometric systems. [*See last diagram of which imagine the two axes in the horizontal plane to be of different lengths.*]

The first of the klinometric systems is the *Monoclinic.* One axis is perpendicular to the other two, which, latter, are inclined obliquely to each other.*




In the *Diclinic* (in which system few if any natural minerals crystallize), one parameter is perpendicular to the second, but inclined obliquely to the third; while the second and third are inclined obliquely to each other.

In the *Triclinic,* each parameter is oblique to, and of a different length from every other.




Finally, the hexagonal crystals are divided by four parameters;

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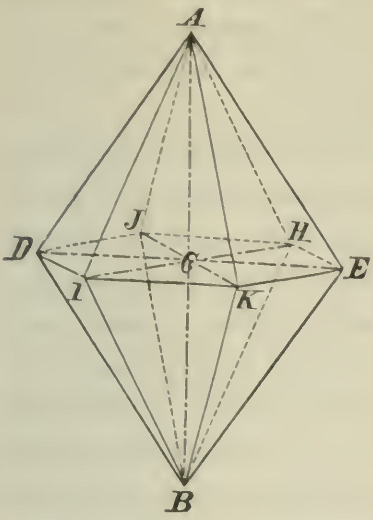
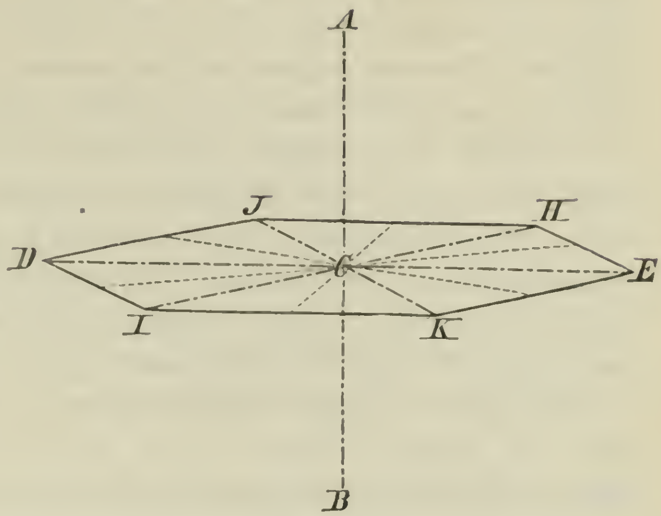
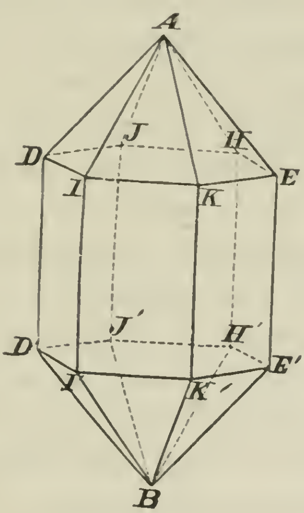
* In this figure the line *F G* has been turned to the right in order to show the shape of the pyramid better.

three in the same plane intersecting each other at angles of 60° and the fourth perpendicular to them.




Observe in one of the cases presented on the screen that the faces most largely represented are those of the prism, *i. e.*, they are parallel to that one of its axes which is selected as the *main* axis and placed conventionally in a vertical position.




Let us consider this with a little imagination. Suppose that in the fluid out of which that crystal was forming itself were an indefinitely large number of minute particles like the iron dust which formed the magnetic curves. If these particles were of the degree of comminution which was alluded to as possible and even probable when the division of matter was carried beyond the range of sense, the equato-

rial region of the particle would be practically abolished, and the particle would be left free to rotate according to the attractions or repulsions of its poles alone. But there is the best of reason for believing that not only in the earth itself but in the minutest fragments of matter there may be two or three or more polarities or directions in which the attractive force is principally displayed.

If these be very numerous and all of the same strength, then, other things being equal, the aggregation of particle to particle will go on in all directions equally, and the result would be a sphere. But if the attractions of one particle for its neighbor be only along certain definite lines within itself, then, the aggregation taking place along these lines, the result would be some figure of plane trigonometry.

At this point we may, without too much license, transfer our thought from the attractive force to that which may be said relatively to measure it (viz: the parameter), and assume that it has been strongest along those parameters which are the longest. Take our prism truncated by pyramidal (and sometimes afterwards by basal planes.)

May we not assume that (so far as each individual crystal was concerned) the *growth force* was greatest along the main axis, and that though growing in all directions, it grew most rapidly in the direction of this axis, at least, until the increased attraction along the other axes impeded the building power along this line, and that its actual direction was the resultant between these two attractions. At such a time the pyramid planes are produced. If these forces remain equal the result will be the 45° pyramid, and, if unequal, the flattened pyramid, or the acute pyramid.

Finally, when the longitudinal growth becomes indefinitely weaker than the lateral, the basal planes appear.

The causes of all these phenomena have been connected by some of the best minds of the day with the changes in direction and intensity of currents of electricity which surround the molecules and even the atoms of all bodies. It was thus that De la Rive sought to accommodate to each other various rival theories.

That electricity, and especially its form of manifestation, magnetism, has much to do with both locking and unlocking the bonds which hold solids together is manifest from many experiments, and in none more than in those usually grouped under the head of electrolysis, or the separation of chemical compounds into their constituents by the electric current.

These phenomena, however, cannot be confounded with those just spoken of as affecting the ultimate molecules and atoms, until it be proven that the result is not due as much to the phase of energy called heat, as to that called electricity. Be that as it may, I have here a simple and beautiful means of illustrating the manner in which bodies pass from the liquid state (or that in which their smallest particles are free to move upon and between each other) to the solid, in which they are firmly held in forms that tell of the nature of the simultaneous forces which acted upon them. [*The poles of an electric circuit immersed in a solution of sugar of lead were here thrown on the screen. Crystallization of lead on the cathode was observed on passing the current through the solution. On changing the direction of the current the fronds of lead dissolved from one pole and formed on the other.*]

But there are other ways besides electrolysis to show this remarkable tendency to systematic arrangement; this building up of crystals before the eyes of the observer; and one of these ways is by evaporation.

When the magma or vehicle in which the minute particles are held is diminished, and the distance between these little masses is decreased, a point is finally reached when their mutual attractions act definitely and permanently, and the consequent architecture is dependent upon their relative force.

Some of these actions lend themselves readily to lecture illustration, while others are controlled by many circumstances not perfectly understood, and therefore impossible always to provide for. The first experiment of this kind to which I will call your attention is one where the mineral thus building itself belongs to the isometric system; but though the absolute attractive force in the crystals of this system is equal in the three directions, it does not follow that at one time, one, and at another time, another of them, should not manifest itself more forcibly as has been hinted, might be the case when the crystal architecture changes from one form to another of the same system. This is apparent in the present case, and the result is a series of fronds apparently like the ice crystals on the window pane of a frosty morning, but in reality when analyzed quite different from them. [*Sal ammoniac was here allowed to evaporate on a glass plate in front of the lantern.*]

Thus the power *temporarily* to manifest a greater growth force along

one parameter than the others makes it possible to have a great variety of *forms* in one crystal *system.*

Compare, for instance, these double pyramids (or octohedra) of arsenious acid which, though so different, belong to the same or isometric system.

The salt now forming is chlorate of potassium which crystallizes in the monoclinic system, but it is not so easy to prove this to an audience.

I shall not attempt here to go into the explanation of this apparatus designed to render these phenomena visible to you, but will simply say that I employ polarized light, which, while unchanged by passage through minerals belonging to the isometric system, is rendered visible, as color, by traversing minerals of all the other systems in certain directions.

[*Sodium bi-tartrate, copper sulphate and mica were used to intercept polarized beams*]

This last experiment brings us to an important fact, by reason of its application to organic bodies. We have seen how light is modified when passing through bodies which have attractive forces greater in one direction than in another during the time of their formation. It could be shown that a plain piece of glass, which in its normal state exercises no influence on polarized light, instantly does so when put to unequal strain in different directions. With the explanations of this fact we have not here to do, but it is enough for our present purpose, that it is a fact. Now, all organic bodies polarize light under proper conditions, and this we have just seen is because all organic bodies are subjected to strains varying in the degree of their force with the directions through the body. But this is tantamount to saying that all organic bodies are the result of that architecture due to polar forces.

Wherein, then, lies the difference between the crystalline architecture of the so-called inanimate nature and that of the highly organized beings which we endow with certain qualities which we deny to other equal masses of matter? It is true that the question is not settled by this resemblance or analogy between the two great kingdoms of nature, but it adds simplicity to the conception of the universe if we may regard all matter as different expressions of one matter, and all force as different modes of one force.

# MEANS FOR EXTINGUISHING FIRE.*

By C. John Hexamer.

## INTRODUCTION.

Before we can enter into a discussion and description of how to command the phenomena of combustion we must understand a few preliminary facts. If we rapidly draw our hand through the surrounding space, we feel a certain amount of resistance. This resistance is due to a gaseous body which surrounds us on all sides, and which we term air, a substance known to the ancients, who tried to weigh it. Aristotle, for example, filled a bladder and weighed it, then exhausted the air and reweighed the bladder, and actually believed he had thereby determined the weight of the atmosphere. It was not, however, until the advent of the experimental era under Galileo and Torricelli that its weight or pressure was determined. It was found at the level of the sea, to be about fifteen pounds to the square inch.

This surrounding fluid consists of two gases, oxygen and nitrogen; not, however, chemically combined, but merely mixed in the proportion—in round numbers—of seventy-nine parts of nitrogen and twenty-one of oxygen. Nitrogen, which is fourteen times heavier (atomic weight) than hydrogen, is a gas entirely negative in its qualities; it does not support combustion, and its purpose in the air is merely to act as a diluting agent so as to make the effects of oxygen less active. Oxygen, the great supporter of life and also the great destroyer in nature, is an odorless, colorless gas, sixteen times (15·95 atomic weight) as heavy as hydrogen. It and its combinations constitute the greater part of our earth. The so called crystalline rocks which consist largely of silicates, contain from forty-four to forty-eight per cent. of oxygen. Water, which is a compound of oxygen and hydrogen, contains one part by weight of hygrogen to eight of oxygen. It is this element which causes all those phenomena which we ordinarily term combustion. Phenomena which it causes while ordinarily diluted with nitrogen (air) are greatly intensified when the element is pure; and even metals, such as iron and steel, when ignited in a globe filled with oxygen, burn with brilliant scintillations.

We are now ready for the question, "What is combustion?" I

* A lecture delivered before the Franklin Institute, January 9, 1885.

would define it as a chemical union of oxygen with some other element or elements, accompanied by an evolution of light and heat, while similar unions of other substances, not with oxygen directly, I will term "chemical combination." Substances which unite with oxygen are termed combustible substances, while oxygen is a supporter of combustion. These terms, although but relatively correct,—as combustion might be defined as an act of a chemical union accompanied by an evolution of light and heat—are for our purposes very convenient and will be retained throughout.

We must, before entering into the subject under discussion, understand what is meant by the temperature of ignition, or the ignition point. It has been found that before a substance can ignite (take fire) either in the air or oxygen, a certain temperature must be reached, and this necessary temperature is termed the ignition point or temperature of ignition. While for some substances this point is very low, for others it is extremely high; for example, nitrogen will only unite with oxygen at the intense heat of the electric spark; while phosphorus burns slowly at 10°C. (50°F.), as may be noticed in the dark (phosphorescence), it does not burn brightly until heated to 60°C. (140°F.), and zinc ethyl and phosphuretted hydrogen ignite in the air at the ordinary temperature.

But most bodies do not unite with the oxygen of the air rapidly enough at ordinary temperatures to produce light and heat, but must be heated for a production of active cumbustion. In the case of the decay of organic matter or the rusting of metals oxidation goes on slowly, producing heat, and the total amount of heat that a decaying log produces in the long time required for its destruction is exactly equal to the amount of heat produced by its rapid oxidation (burning) in a stove. We, therefore, distinguish between quick and slow combustion.

The temperatures of different flames vary greatly. Bunsen found that the temperature of the flame of hydrogen burning in air is 2,024°C., temperature of a hydrogen flame burning in oxygen 2,841°C., carbonic oxide 1,997° when burning in air, and 3,003°C. when burning in oxygen.

In order to measure the quantity or strength of a material or force, we must have a measure or standard of comparison. The standard for the measurement of heat, if the expression be allowed, as heat is a force and not a material, is the "thermal unit," the amount of heat required to raise the temperature of one cubic centimetre of water one

degree Centigrade. This measure is now almost universally employed by scientists, although the old English calorie unit, the amount of heat required to raise one pound of water one degree Fahrenheit, is yet sometimes employed. Two other units are also used; in Germany, the amount of heat required to raise one kilogramme of water one degree Centigrade is much used; while the unit of one pound of water to one degree Centigrade is sometimes employed.

COMBUSTION IN OXYGEN.

| One gramme of | Thermal units. | Observer. |
|---|---|---|
| Charcoal | 7,273 | Lavoisier. |
| " | 7,167 | Dulong. |
| " | 7,912 | Depretz. |
| " | 7,714 | Grassi. |
| " | 8,080 | Favre and Silbermann. |
| " | 7,900 | Andrews. |
| Diamond | 7,770 | Favre and Silbermann. |
| Natural graphite | 7,811 | " " |
| Gas carbon | 8,047 | " " |
| Hydrogen | 34,462 | " " |
| " | 33,808 | Andrews. |
| " | 34,180 | Thomsen. |
| Sulphur | 2,220 | Favre and Silbermann. |
| " | 2,307 | Andrews. |
| Phosphorus | 5,747 | " |
| Zinc | 1,301 | " |
| Iron | 1,576 | " |
| Tin | 1,233 | " |
| Copper | 602 | " |
| Marsh gas | 13,063 | Favre and Silbermann. |
| " | 13,108 | Andrews. |
| " | 13,120 | Thomsen. |
| Olefiant gas | 11,858 | Favre and Silbermann. |
| " | 11,942 | Andrews. |
| " | 11,957 | Thomsen. |
| Carbon monoxide | 2,431 | Andrews. |
| " | 2,403 | Favre and Silbermann. |
| " | 2,385 | Thomsen. |

Numerous experiments, made by different scientists, have proved beyond a doubt that a constant quantity of heat is given off when the same weight of the same substance burns to form the same products of combustion, whether the combustion proceeds slowly or rapidly. Numerous measurements of the amount of heat disengaged by the combination of different substances with oxygen have been made, of which those of Andrews, Favre, Julius Thomsen and Silbermann are the most correct. The above table compiled by Roscoe, shows the heat of combustion in thermal units for one gramme of substance burnt.

WATER.

Water was the first material employed to extinguish fire. One of the best materials and means for extinguishing fire are well-filled galvanized iron water-buckets. These should have conical bottoms, so that they can not be used for other purposes than that for which they are intended. They should be kept filled at all times. A very good method of keeping them filled is to appoint a special man for this purpose, and fine him one dollar for every bucket which is found empty. It should be the particular duty of the watchman to examine the buckets daily and report on their condition; and, in order to increase his surveillance, the money obtained for fines should be presented to the watchman, whose vigilance in this respect will thereby be greatly increased. Reliable automatic devices are always preferable to means depending on human agency, and for this purpose the "automatic electric low water alarm" is highly recommended; this is a device which sets an electric bell in the superintendent's office into operation as soon as one quarter of the contents of a bucket evaporates, and continues to ring until the bucket is filled. Buckets should be of iron, not wood, as wooden buckets, when they are dry or partially empty, shrink and become leaky. They should be well covered, first, with a zinc coating, which is generally called galvanizing, and then with good tar or asphaltum paint, put on hot, which will cause buckets to last much longer than they otherwise would. The word "Fire" should be painted on them with large letters—red is to be preferred as that color can be seen best—so that one may know their purpose and readily discover them in case of emergency. All factories should have trained bucket brigades, as it is not easy to use a bucket properly. It seems an easy matter to pour water upon a burning substance; but when we consider that, in the majority of cases, it is impossible to reach the point of fire, and

that, therefore, water must be thrown from a distance, it is self-evident that it is quite an art to throw the contents of a bucket on the spot necessary, without spilling or wasting the greater part of it. In order to make a bucket brigade efficient, they should practice once or twice a week. Every room which contains buckets should contain large casks with wide opened tops, so that the buckets may be readily refilled. I frequently find casks with the top so small that it is almost impossible to introduce the bucket into the opening and procure water, and it would be utterly impossible, in case of fire, when people are frightened to a craze. It is a notable fact that more than twice as many fires are extinguished by buckets than by any other means. The importance of having factory buildings properly equipped with them is therefore obvious.

### PUMPS.

The oldest and first-described fire pump is that described in the Spiritalia of Hero, 150 years B. C.

[A slide showing this pump was projected on the screen.]

One of the best and strongest pumps, in places where water power is used, is the French Rotary. Its chief merit lies in its great strength. Its operation is due to the displacement of water between the teeth of two coarse gears. Its construction is very simple. There are no weak and small parts which break; no valves which require constant attention, while it is very durable and wears out slowly. It should take its supply from the flume, and should be about 18 inches above the water level, so that it may not be flooded. Driving belts should not be used, as a fire will soon destroy these. In the same way bevel gears are objectionable, because they are apt to slide, causing the various parts to stick, and the pump to become worthless when most needed. Friction gears, when the pump is strongly erected, are perhaps best; although, when the heat becomes great, they become warped, but stand longer than any other arrangement.

[A number of slides, showing the construction and the general arrangement of water-power pumps, were then shown.]

### STEAM FIRE PUMPS.

The pre-requisite conditions in choosing steam fire pumps are, that they should be simple, strong, and, which is included in the foregoing, there should be as few small and weak parts as possible, as these are

apt to get out of order and break. All fire pumps should be supplied with a relief valve (which relieves excessive pressure), as when the pump is running at full head, hose is frequently bursted, and as it is often impossible to reach the pump during the fire, the hose with which it is connected becomes worthless when most needed, as was the case at the fire of a large chemical works a short time ago. A fire pump should be placed where it is least exposed to fires; preferably outside in a fire-proof compartment, so that the attendant may have access to the pump to the very last, and the pump may still work even if the entire remainder of the property be destroyed.

[A number of slides, showing the general construction of the various fire pumps, were projected on the screen.]

VERTICAL PIPES.

I do not think much of the outside vertical, or, as they are sometimes called, Palmieri pipes; which are run along the outside of buildings, extending to the roof; the intention being that, in case of fire, the Fire Department will attach the engine to the lower end and the hose to the connection on the roof. It has, however, been demonstrated by experience, that, with few exceptions, as in the case of a few very high buildings, firemen prefer to carry their hose on their ladders to the top of the building, and such pipes are, therefore, of little value in case of fire, as firemen will not use them.

Inside stand-pipes or vertical pipes, on the contrary, are of great importance. These should be connected with tanks of large capacity or with good force pumps, so that strong pressures may be obtained in them at all times, as the pressures of the City Water Departments, especially on higher stories, are inadequate. We frequently, in our Philadelphia Specials, find vertical pipes connected with the City water supply, which, on being tested, will throw a stream of not more than ten or fifteen feet. Care should be taken to place all vertical pipes away from exposed positions. These pipes should never be placed along walls exposed to the wind, as, in winter, the cold will cause the water to freeze and burst the pipes, the arrangement becoming worthless. They should always be placed in positions which will be least apt to be destroyed by fire, and which, in case of fire, will be least exposed to flames and smoke. Fire-proof stairway houses are well adapted for this purpose, as firemen in them are able to fight the fire until the last moment, as they know they still have a fire-proof way of retreat, and can, at any moment, protect themselves by

closing the fire doors which lead into the stairway house. Vterical pipes should be of ample size, so that the requisite amount of water can be drawn from them. A good pressure in it is the pre-requisite of an efficient stand-pipe.

[A number of slides were shown, explaining the various modes of erecting stand-pipes.]

### HYDRANTS.

In the ordinary hydrant, the water is at all times contained in it.

[This was shown and explained by a number of stereopticon views.]

In order to keep the water from forcing into the upper portion of the hydrant, which is apt to deteriorate it, causing parts to corrode, several devices have been constructed, such as the Matthews', and the Chapman hydrants, in which the water is turned on by valves in the lower end of the hydrants, which is, therefore, eliminated from the upper parts of the plugs. A similar construction is used for our ordinary fire plugs. The name, "fire plug," is derived from an English expression, and in its original appellation is entirely correct. An English plug is a device for reaching water, in the following manner: The main water supply, running along the street, is punched with holes at various parts, and these are closed by wooden plugs, tightly driven in. On top of these a box is fitted, which is filled with manure or straw, in order to keep the water from freezing. In case of fire, the fire department must first remove the manure or straw, knock out the wooden plug, and make connection with the opening, and pump the water from the pipe. Plugs of this kind are still used, to a certain extent!

It was through the admirable labors of the father of a Vice President of this Institute, Mr. Frederick Graeff, that plugs were first invented and introduced in our city and throughout the United States, and their introduction has now become general in every civilized country in the world.

[A number of slides, illustrating the various hydrants, was shown.]

### VALVES.

Only straight valves should be used for turning on water. Mr. Woodbury states he found, in a number of experiments made by him at Holyoke some time ago, that a two-inch globe valve reduced the pressure from 80 to 40 pounds per square inch.

[This was further explained by means of slides projected on the screen.]

A valve or hydrant which is not water-tight, on being closed by hand, without great effort, is to be deprecated, and should never be employed, as it is liable to break, on account of the excessive strains applied to certain parts when it is opened and closed. Jenkins' and Chapman's straightway valves can be recommended.

[These were shown and explained by means of slides.]

It is absolutely necessary that all valves in a factory should open in one direction only. I have frequently found that even the same factory contained valves which opened in different directions. It is no wonder, therefore, that mistakes are made, especially when people are highly excited as in case of fire. In order to overcome this difficulty, valves should be labelled with an arrow and the word "*open*" painted on it conspicuously, so that any person, even unacquainted with the valve, may be enabled to open it properly. It is an unfortunate coincidence that even among mechanics and engineers, the words right-hand and left-hand valves do not have the same significance. In some parts of the country the word "right-hand" signifies the motion of the hands of a clock, while in other districts, as used even by some persons in the same district, the term signifies the opposite. It would be well if conventions would take the matter in hand and settle the term once for all.

Chapman's gate, which was introduced some time ago, is a very good one, as it can be opened or shut by one turn of the hand to every inch diameter of the gate. For example, a six-inch gate is shut or opened by six turns of the hand wheel, etc. As further advantages for the gate are claimed, "that it opens in the natural manner, advancing stem, full opening, with the utmost quickness of motion, without water hammer."

[Several gates and methods of construction were then projected on the screen.]

## HOSE.

I prefer unlined linen hose for inside use even to more expensive kinds. Woodbury states that twelve samples from different manufacturers, weighing from three and three quarters to four ounces per foot, burst when new, at pressures of from 420 to 650 pounds per square inch. Several experiments made by myself, with similar hose,

gave even better results, bursting at pressures, between 415 and 670 pounds per square inch; but it is only proper to state that the best samples were furnished me for the express purpose of testing, and may, therefore, have been of extra strength.

In order that a hose shall remain in good condition, it must be kept dry, and should not be wound on reels. A hose, on a reel, after some time, on being unreeled, assumes a winding form similar to an Archimedean screw, and when run off in a hurry, is apt to *kink*, and cut off the supply of water at times when it is most needed. Hose should be kept on a pin, and should be laid on with looping ends, as loose twine is frequently kept on a nail..

[The manner was then shown by a sketch on the board.]

The pin should be protected with a round, broad saddle or back, so that the hose may not crack, as it will when hanging on too sharp an edge. If hung properly on a pin, it may be drawn off without the slighest danger of *kinking*.

It is absolutely necessary that uniform couplings should be introduced throughout, not only for regular fire departments, but also for factories. The old screw coupling labors under the serious disadvantage that if the hose is not permanently attached to the hydrant, in the event of fire and excitement, it is difficult to attach the hose properly. For this purpose Jones' patent coupling, which is now used in most of our public fire departments is excellent, as the hose may be quickly attached, even by excited persons. Care must, however, even in this simple coupling, be taken to press the joints together tightly, as complaints are often made by incompetent persons, that the joints leak. If they are put together properly, no leakage will occur. In the ordinary Jones' coupling the rubber strip, which forms the tight joint, extends a short distance into the coupling, and therefore, to a certain extent, retards the flow of the water and reduces the pressure, it has been claimed by some, as much as 20 per cent. Clay's coupling, in which the rubber strip does not protrude into the opening, or water way, is an important improvement, as it does not retard the velocity or pressure of the stream. A great advantage with the Jones' coupling is that with an increase of pressure, up to about 300 pounds to the square inch, the joints become tighter, and are, therefore, less liable to leak.

## NOZZLES.

I still prefer the old leather nozzle, with a metal tip, to the long

metal nozzles, which are now much used. A leather nozzle may be bent in all directions which one of metal cannot be, and as in fighting fire it is very frequently necessary that the fireman shall stand behind a projection, and direct the stream by bending the nozzle without exposing much of his body to the heat and flames, the importance of short metal nozzles or leather nozzles is evident. Morse's monitor nozzle is an important invention, as by simply turning a crank the nozzle may be turned in any position and held there. The so-called "spray" nozzle is a new and valuable invention, as it is frequently impossible for firemen to see on entering a burning building, on account of smoke, sometimes created by insignificant fires, which it is impossible to detect for some time, on account of the smoke generated. The spray nozzle produces a fine spray, which precipitates the smoke around it, giving the firemen an opportunity to see and follow up the fire.

Drip couplings are good for places in which the hose is attached to hydrants at all times. They consist of couplings with small openings or slots in the bottom, so that any contained water or water created by the leakage of valves, will not reach the hose (and which would deteriorate it), but will escape through the slot before reaching the same.

| Pressure at Hydrant. Pounds per sq. inch. | Discharge per minute. Gallons. | Distance reached by jet. | |
|---|---|---|---|
| | | Horizontal feet. | Vertical feet. |
| 15 | 84 | 54 | 26 |
| 20 | 98 | 62 | 35 |
| 25 | 112 | 72 | 45 |
| 30 | 122 | 80 | 52 |
| 35 | 132 | 88 | 60 |
| 40 | 140 | 96 | 67 |
| 45 | 149 | 103 | 75 |
| 50 | 157 | 111 | 80 |
| 55 | 165 | 118 | 88 |
| 60 | 172 | 125 | 93 |
| 65 | 180 | 132 | 101 |
| 70 | 186 | 139 | 106 |
| 75 | 193 | 145 | 111 |
| 80 | 199 | 150 | 116 |
| 85 | 205 | 156 | 121 |

The above table, taken from the excellent work of Mr. Geo. A. Ellis, serves as a basis for estimating the diameter of distributing mains, for the passage of water through them, and is found for 100 feet of rubber hose and one inch smooth nozzle:

[A number of lantern projections illustrated the various nozzles.]

TANKS.

Tanks should be of large size, even larger than is usually thought to be sufficient. They should be provided with an overflow valve, and the contents should not be allowed to freeze. This can be prevented by passing an exhaust steam pipe through the tank, or by mixing the water with salt, which will at the same time prevent the formation of organic slimes, which are objectionable. The tank should be in a position least exposed to the cold north winds. An alarm valve should be introduced in the tank, which gives an alarm, either by whistle or bell, whenever the water falls below a certain height in the tank. A better arrangement is an automatic electric alarm, which can be put in connection with the office of the superintendent, and gives the alarm there whenever the water falls below a certain height in the tank, being at the same time a tell-tale on the engineer in charge of the pump. Tanks should always be placed on the strongest part of a building, and on that part which will be apt to stand longest in case of fire. A fire-proof stair-way house, well sheltered from the flames of the surrounding buildings, is an excellent position.

SPRINKLERS.

For some years past mills have been provided with perforated sprinkler pipes, which extend through the mill lengthwise, and are perforated with numerous holes, one-tenth of an inch in diameter and from eight to ten inches apart. When a fire occurs, the water is turned on by a valve outside of the building, water rushing into the pipes, and being discharged through the openings. The great objection which is found to this system in practice is that the water is not confined to those spots only at which the fire occurs, but is distributed over the entire premises provided with such sprinkler pipes, and frequently it was found that the damage done by the water was inestimably greater than that which would have been done by the fire.

Another great objection to it, is, that it requires human help in order

to turn it on, and all who have had experience in *fire technology* know of how little this is to be relied upon in case of fire.

To overcome these various objections, automatic sprinklers were invented several years ago, the earliest forms being turned on by means of levers with weights attached to them, which were held in position by strings, which, on burning through, released the lever and set the sprinklers in operation. At present, automatic sprinklers consist of a system of pipes, which extend near the ceiling, and the water is released, by valves attached to the pipes, by the heat created by the fire. The valves are kept closed by means of fusible solder, which melts at a temperature of 150°F. or over. The heat which arises from the fire melts the solder joint of the valves immediately over the place where the fire occurs, the water is expelled and is delivered just where it it is needed at the time, and not thrown over the entire premises, as was the case with the former sprinklers.

Automatic sprinklers are divided into two great classes, (1) *sealed sprinklers*, such as the Rose, Bishop, Burritt, Parmelee, etc.; and (2) the *sensitive*, such as the Neracher, Kane Bros., Brown & Hall, Buell, Burritt, Grinnell, etc.

Automatic sprinklers have now been in use for about twelve years, and a series of tests made by Mr. Woodbury shows that the fusible solder has not deteriorated in that time, and still possesses all its valuable properties. It was formerly thought that the solder would in the course of time, through corrosion (oxidation and pressure), become worthless, which these tests seem to disprove. The effectiveness of automatic sprinklers is shown by the fact that out of 110 fires in factories in which they were introduced, and of which the amount of damage was accurately determined, for 67 or 60·9 per cent. no damage was claimed; for 12 or 10·9 per cent. the damage done was less than $250; for 8 or 7·2 per cent. the amount of loss was between $250 and $500; for 11 or 9·9 per cent. between $500 and $1,000; for 12 and 10·9 per cent. between $1,000 and $20,000.

I consider automatic sprinklers to be specially valuable in those parts of factories in which finely divided organic substances or dusts are created, as, for instance, in the picker and card rooms of textile mills, in flour mills, malt mills and so on, as the water projected from the ceilings precipitates the dust, and therefore removes one of the most dangerous sources and causes of fire, and prevents the fire from extending further by means of the ignitible dust.

[The various sprinklers which have been tried and found effective were then shown and explained by means of slides projected on the screen.]

By a series of tests made by Professor Morton, President of the Stevens' Institute, for the New York Board of Underwriters, it was shown that the tank which supplies the sprinklers should in every case be at least ten feet above all pipes; and the following table shows the amount of water which is used in fifteen minutes for pipes of the following diameters, to which the number of sprinklers indicated are attached:

*Tank, ten feet above all pipes.*

| Diameter of Pipe. | Number of Sprinklers Supplied. | Gallons running for fifteen minutes. |
|---|---|---|
| ¾ inch | 2 | 212 |
| 1 " | 4 | 424 |
| 1¼ " | 5 | 530 |
| 1½ " | 9 | 954 |
| 2 " | 16 | 1,696 |
| 2½ " | 25 | 2,550 |
| 3 " | 36 | 3,816 |
| 3½ " | 49 | 5,194 |
| 4 " | 64 | 6,784 |
| 5 " | 100 | 10,600 |
| 6 " | 144 | 15,264 |

## STEAM JETS.

Live steam is one of the best agents we possess for extinguishing fires in small inclosed compartments. All small rooms, such as picker and drying rooms, should be supplied with ample sized steam jets. In order to make steam jets effective they should be turned on from the outside, the valves being located in some secure position, as the first impulse of every one, in case of fire, is to run out; when reason returns, a person is more apt to turn on a valve from the outside than he would be to enter the burning room and turn the valve. But, in order to make a steam jet absolutely effective, it should be automatic. For this purpose I invented the following device: On the steam supply pipe a ring is tightly fitted, to which is attached a rod, which, on its

end, is formed into a fork-like projection. On top of this fork a bar is placed, to which a rope, impregnated with substances which will cause it to burn rapidly when ignited, is attached; and the two sections of the rope are held together by means of a fusible solder joint. This rope serves to hold in place a lever to which a weight is attached. This lever is in connection with a valve. I use for this purpose a spring valve, constructed by the Bellfield Valve Company, which will not corrode, and which works easily and well in all cases. To the small rod, which rests on the open fork, a rod is attached, which passes through a small slot or pipe in the wall to the outside, and to it a convenient handle is attached. Now, let us suppose that a fire occurs in a picker room, and that, as is generally the case, the employés run out. Should one of them be cool headed enough, he would go to the outside, pull the handle, and thereby draw the bar, which rests loosely on the open fork, from the fork; the lever would drop and open the steam into the room. But, let us suppose that the employé has not the proper amount of coolness, and runs away without turning on the steam from the outside. Then the temperature will rise to 160°F., the temperature at which the fusible solder joint will melt and separate (the solder joint may be fixed for any temperature by altering the composition and proportions of the ingredients of the solder); the lever will be released, as in the former case, and the steam turned on. Let us, however, suppose that through some unforseen accident the solder joint would not work, then we still have as a third means the extremely inflammable rope, which would soon be ignited, and burn through, thus causing the valve to be turned on. We therefore have three alternatives, one of which would undoubtedly come into play.

In all steam jets, be they automatic or otherwise, valves should be used which can be turned on readily. I have frequently found valves so tightly corroded and stuck fast that they were worthless in case of fire.

## EXTINGUISHERS.

Extinguishers contain water which is of value on account of the carbonic acid gas which it contains, which replaces the air, the burning body being at the same time incrusted with a layer of salts.

Carbonic acid is an excellent extinguishing agent in any form. I suppose you all have seen the experiment of extinguishing a number of candles placed in a trough, by pouring carbonic acid gas in one end and allowing it to flow through.

One of our large soda water establishments has extinguished several small fires in their building and neighborhood by means of the carbonic acid contained in their soda water appliances. A druggist extinguished a small fire of benzine, which had ignited in his store, by a bucketful of soda water, which he sensibly drew from his fountain and poured upon it, instead of using ordinary water, which would have been of no avail.

Extinguishers, in the proper sense of the term, as first used, consist of apparatuses containing gas, which in case of fire is liberated, displacing the air and thereby extinguishing the fire. The apparatus of Cartier consists of a cylinder of sheet-iron which is tested to a pressure of eighteen atmospheres. To both ends are attached bottoms of sheet steel, and by means of a specially constructed filling pipe in the upper end, water and bi-carbonate of sodium are poured and the pipe tightly closed, and when used tartaric acid is injected by a special device, which causes the formation of carbonic acid gas and sodium tartrate. These are partially dissolved by the water, and the gas produces a pressure of from four to seven atmospheres on the contained liquid, which, when the cock of the nozzle is opened, produces a strong stream. Shaeffer and Budenberg use the same substances under a pressure of ten atmospheres.

Instead of the expensive tartaric acid, Zabel and Dick first substituted sulphuric acid. In Dick's apparatus the sulphuric acid is contained in a separate glass, which, in case of fire, is broken and then reacts on the bi-carbonate of soda. In Zabel's apparatus the sulphuric acid is contained in a glass cylinder, which is turned upside down in case of fire, and the cover, thereby opening, allows the acid to flow out and mix with the salts; thus producing the gas.

Similar to these are the apparatuses of Masnata, who releases carbonic acid gas with sulphuric acid and the carbonates of different elements; and the apparatuses of Baragwanath and Van Wisker.

Among the efficient American extinguishers may be mentioned the Harkness Pneumatic Extinguisher. A new extinguisher called "The Climax," is before you. In this, sodium bi-carbonate and oxalic acid is used. The extinguisher is charged with water, and the dry material is placed in two receptacles above it. When used, the dry material is dropped into the water by relieving the bottoms of the receptacles which are attached by hinges; carbonic acid gas is generated and oxalate of sodium formed, the charged water being ejected by

means of a small pump attached to the apparatus. This is an excellent extinguisher, while used on the floor, as it may be frequently refilled, fresh substances being added, and the pumping continued; but it cannot be used on ladders, as is necessary in reaching ignited substances on high walls or ceilings.

Platt's extinguisher, which has been kindly loaned me for this evening, has been used with great success for many years. Its great value consists in its simplicity, as the most ignorant workmen can be readily taught to use it. It is put into operation by merely turning the valve handle as far to the left as possible, and turning the extinguisher upside down. This firm also manufactures small extinguishers, which can readily be carried on the back, and which can be used on ladders for reaching substances which cannot be reached by a stream from the ground. These extinguishers were employed in the Electrical Exhibition.

In selecting fire extinguishers we must, as in choosing all other machinery, take those which are simplest and least apt to get out of order, and those which contain substances, and arrangements by which the metal of the apparatus is not corroded, (as many are put into the market which will last but a few years, on account of the corrosive nature and method of placing the ingredients.)

Of late, so-called hand grenades have been used. These devices, though highly ornamental, I do not approve. The extinguishing material is contained in bottles, which must be broken in order to cause the extinguishing liquid to be spread over the flames. It is exceedingly difficult to break the bottles over a fire, by taking two bottles, as is generally advised, and breaking them over the point of danger; while we frequently find the bottles, which are strongly made, are not broken by throwing them into inaccessible places, or into such materials as burning yarn, raw stock, waste, etc. The joke of a prominent underwriter when he first saw them is perhaps not out of place, who said that in case of fire one would be apt to look for a corkscrew to remove the cork in the bottle before putting out the fire. The wire racks in which some grenades are placed are valuable additions. These consist of wire baskets so arranged that when the grenades are removed from them, a fire alarm is given.

EXTINGUISHING POWDERS.

Bucher's extinguishing powder partially rarefies the air, by heating the atmosphere, and also withdraws air in enclosed spaces, producing sulphurous acid, which tends to smother the fire. According to Heeren, the value and extinguishing results of burning di-sulphide of carbon does not consist in the absorption of oxygen from the air, and the effects of burning Bucher's powder are not produced by the resulting gases replacing the air, but, he believes, that the gases which are thus caused, consisting largely of sulphurous and carbonic acid gas, having a higher specific gravity than air, prevent all draught or circulation around burning substances, and that, therefore, air cannot reach them and supply the oxygen necessary for combustion. Liquified sulphurous acid is one of the best agents for extinguishing fire.

Bucher's powder, as prepared by Wittstein, contains 60 parts of saltpetre, 36 parts of sulphur and 4 parts of charcoal. Schweizer prepares the powder with the following composition: Saltpetre, 58·53 parts; sulphur, 36·33 parts; charcoal, 3·14 parts; sand, 75 parts, and oxide of iron, 1·25 parts. Heeren prepares Bucher's powder in the following manner: Saltpetre, 63·73 parts; sulphur, 28·93 parts; charcoal, 3·80 parts, and oxide of iron, 3·54 parts.

The ingredients are not powdered quite as finely as for the manufacture of gunpowder. They are then mixed and placed in small packages of pasteboard, so tightly packed that only a very sharp instrument can separate the particles. The composition can readily be ignited and burns (without exploding) with a strong white flame and strong penetrating odor and smoke. Out of every pound, 4·82 cubic feet of gas are produced, consisting of 2·36 cubic feet of sulphurous acid, 1·10 cubic feet of carbonic acid, and 1·36 cubic feet of nitrogen. According to Bucher, about one pound of the material should be used for every 240 cubic feet of space. In case of fire, the powder is thrown into the fire, whereby the results above described will be produced.

These powders are only of value in small enclosed rooms, without many ventilating openings, and has practically proved valueless in places exposed to great draughts. One great objection to it is that it is extremely dangerous to life, as several cases of severe accidents have occurred in Europe. It has been of great value in drying rooms, where substances coated or impregnated with petroleum compounds are dried; Dorn reports for instance, a case in which a severe fire in the drying room of an oil cloth factory was extinguished by it.

The extinguishing composition of Zeisler consists of 60 parts saltpetre, 36 parts sulphur, and 4 parts charcoal and lime. The mass, after being mixed, is compressed into cartridges by means of a hydraulic press, and several of them are connected by a hermetically enclosed easily ignitable fuse.

Gruneberg's composition consists of 20 parts potassium chloride, 50 parts potassium saltpetre, 50 parts sulphur, 10 parts rosin and 1 part magnesium di-oxide, tightly packed in the form of cartridges.

Johnstone's powder consists of equal parts of potassium chloride, rosin, potassium saltpetre and black oxide of manganese, moistened with water-glass, and then pressed into briquettes, a number of which are shipped in one box, being connected by a fuse which can readily be ignited and thus ignite the mass. The box being suspended near the ceiling.

### OTHER MEANS.

Other means for extinguishing fire which have been used are di-sulphide of carbon, liquified sulphurous acid, the gaseous products from under the boiler, water-glass, salt, magnesium chloride, sulphate of aluminium, ammonia gas, borax, sodium phosphate, Glauber salts, soda, etc.

Burning fats, rosins, pitch, etc., can be successfully extinguished by placing wire gauze of very fine mesh over the burning mass. The reason for this, which explains also the efficiency of the Davy safety lamp, is, that flames are not transmitted through wire gauze, as the wire being a good conductor, conducts away the heat, preventing the flames from passing through it.

Sand is a very good agent for extinguishing fires originating in pitch, tar, petroleum and its products; as in this case water will be of little value, while sand, when piled upon burning substances, cuts off the supply of oxygen from the air, causing the flames to be extinguished.

### FIRE BRIGADES.

Fire brigades were in use among the ancients. Thus we find under Augustus Cæsar, A. U. C. 732, that the Romans had a fire brigade ot 600 freedmen.

Organized fire brigades in factories, should be drilled at least once a week. Every man should have his special duty assigned him and know exactly what to do in case of fire; only these men should be

allowed to take part in extinguishing fires; strict rules should be promulgated, that every one not belonging to the fire brigade must remove from the premises as soon as the fire alarm is given, thus giving the firemen room to work. The brigade should be drilled at a different hour weekly, for if they be always drilled at the same time, they will be prepared for the event; will go through their drill at this time in good manner, but when a fire starts at another time they may be excited and slow to get to work. For this reason it is necessary that the chief of the brigade give the fire signal at different times every week, and thus get the department on duty at times when they do not expect it. He will thereby, accustom his people to get to work rapidly at all times, and as they do not, at the time when the alarm is first struck, know if it is merely an alarm or an actual fire, in the course of time get over the excitement which is generally incidental to such an occurrence. It is absolutely necessary, that the chief shall insist on all occasions that his men get to work immediately. If he allows slovenly practice, he will have the same state of affairs in case of fire.

### WATCHMEN.

A good watchman is of great advantage in a mill, but in order to effectively control him, watch-clocks or time detectors, as they are more frequently called, should be introduced, as a watchman, without a watch-clock, in the majority of cases, is unreliable. It is a standing joke of the Patrol that the first thing they have to do in arriving at a fire is to save the watchman, as he is almost invariably sound asleep and would burn to death.

[Various time detectors were shown on the screen, such as the stationary clock, to which a button lever is attached, which must be pushed at required times, either hourly or half hourly, as the rounds may be, and will the next morning, from the perforations on a time card, show the superintendent if the watch has been properly carried on. The Buerk's time detector which consists of a clock, which the watchman carries with him, while the keys are fastened. The marks on the card next morning show whether the watchman has made his rounds.]

Special care must be taken to have the keys or stations provided in all dangerous places where fires are likely to originate, so as to keep them under constant supervision.

A clock gains in value by simplicity, and the manner in which it is protected from being tampered with by watchmen as it is frequently to their interest to conceal breaches of discipline by so doing.

For this reason an electric time detector is an excellent arrangement it consists of buttons placed at the various stations, the watchman, in pressing these, gives a signal impression on a time card in a clock in the superintendent's office. It is very difficult for the watchman to tamper with this apparatus as his only means is to cut the wire, which in well managed establishments would cause his immediate dismissal.

[Various electric watch-clocks were then thrown on the screen and explained.]

## FIRE ALARMS.

The first fire alarms used were either large bells, gongs, or whistles which, by their peculiar sound, would make known that a fire had originated. The ordinary steam whistle is an excellent arrangement. This consists of a hollow hemisphere against which the steam is blown from a valve, the metal is set in vibration, imparts this motion to the contained and surrounding atmosphere, setting this also in vibration, thus producing a sound. Where steam whistles are used as fire alarms it is necessary that these should be very loud and have a shrill peculiar sound, different from all others in the neighborhood, so that persons may at once recognize it.

Automatic fire alarms have been introduced for some time. One of the oldest is that of Joseph Smith, first introduced in 1802, which was set in operation by means of a cord, which being burnt through released a lever in connection with a steam whistle or a bell.

Another apparatus used was a wire extending over a mercury receptacle, connected with a lever, which it held in place. When the temperature rose, the mercury contained in the receptacle touched the wire, amalgamated the same, which caused the tensile strain on the wire to part it, relieve the lever and cause an alarm. These devices were never of much practical value.

Of late the so-called thermostats have been introduced. These are of various construction; some consisting of strips of different metals, tightly fastened together, which, by their unequal expansion, bend, thereby forming contact with a metal strip, which closes an electric circuit, causing an alarm to be struck at the fire station.

Another consists of a bulb containing mercury, into the bottom of which a wire is melted, and in the upper end a wire which does not touch the mercury, is hermetically sealed. When the temperature

increases, the mercury in the column rises and touches the upper wire, forming contact, closes the circuit, and gives the alarm at the station.

Another very ingenious device is that of Fein of Stuttgart, which consists of an arrangement held in place by means of a spring, the spring in its turn being held in place by a fusible cylinder. The temperature rises, destroys the fusible cylinder, the spring is released, and contact is made, an electric circuit formed giving the alarm.

[A number of these devices were then thrown on the screen and explained.]

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HEAVY RAINS AND VOLCANIC ERUPTIONS.—M. Guy accounts for the heavy rains in the spring of 1884 by the condensation of vapor on the particles of volcanic dust which gave the brilliant twilights of the preceding autumn and winter. He cites in confirmation of his opinion the conclusion of Aitken's memoir in the transactions of the Royal Society of Edinburg for 1880 81. The eruptions of Skaptar-Jokul in Iceland in the beginning of May, 1873, of the new volcano in the Gulf of Sicily in the early part of July, 1831, of Cotopaxi in 1856, and of Vesuvius in 1862 were followed by brilliant sunsets and also by heavy rains.—*Comptes Rendus*, June 23, 1884. C.

SOLDERING ALUMINUM.—The use of aluminium is greatly limited by the difficulty of soldering it to itself or to other metals. M. Bourbouze begins by tinning the pieces which are to be joined ; but, instead of using pure tin, he employs alloys of tin with other metals, giving preference to those of tin and aluminium. For articles which are to be worked after soldering, a good alloy is composed of 45 parts of tin and 10 alumnium, which is malleable enough for hammering, punching and turning. When there is to be no working, the soldering alloy will require less aluminium and it can be applied in the usual manner by a common soldering iron.—*Comptes Rendus*, June 16, 1884. C.

LUNAR AUREOLE.—On the 4th of July, 1884, at 9 h. 30 m. P. M., Tacchini observed that the moon was very red and surrounded by a reddish halo which had a breadth of about a lunar diameter ; the tint was nearly that of copper. The phenomenon was observed by one of his assistants and by other persons. A similar appearance was presented on the following evening, but the tint was much feebler. On the 6th the sky was cloudy, and subsequently there was no repetition of the phenomenon. During the three nights mentioned there was great humidity, the air being nearly saturated through the night while during the day the humidity fell to ·40.—*Comptes Rendus*, July 15, 1884. C.

# The ELECTRICAL DETERMINATION of the VELOCITY of PROJECTILES.

By Prof. Edwin J. Houston.

Various electrical contrivances have been devised for the accurate determination of the velocity of projectiles. These may be divided into three classes, viz.: the Ballistic Pendulum, invented by Robins in 1740; the Gun Pendulum, employed by Count Rumford, 1781; and an Electrical Method, first suggested by Wheatstone in 1840.

An excellent display of such appliances was made at the International Electrical Exhibition of the Franklin Institute, by the United States Ordnance Department, under the charge of Captain Otto Ernst Michaelis, of the Frankford Arsenal.

In the ballistic pendulum the velocity of a projectile is calculated by means of the deflection which it produces in a freely moving pendulum, the bob of which is of a size sufficient to receive the impact of the projectile. The ball, penetrating the heavy pendulum bob, imparts to it a velocity which is calculated from the arc described by the pendulum, and the time in which the whole mass vibrates. A projection below the bob is employed to mark the extent of the deflection of the pendulum.

The gun pendulum depends for its action on the measurement of the arc of recoil of a gun, suspended in a horizontal position, so as to freely vibrate.

The electrical method consists essentially in causing the projectile in its flight to successively rupture two targets formed of wire screens. Each of these screens is placed in the circuit of a voltaic battery and an electro-magnet. Each electro-magnet has a pencil so attached to its armature, that its point is held near, but not in contact with the surface of a revolving cylinder. As the ball pierces the wire screens it breaks the circuit of the electro-magnets, and permits a spring to move the armatures from the magnet poles, and so permit the pencil to make a mark on the surface of the revolving cylinder. The distance between the screens being known, as well as the velocity of rotation of the cylinder, the distance between the two markings will readily give the velocity of the ball between the two screens. This velocity, which will of course be the mean velocity, is appreciably the actual velocity of the ball at the middle point of the distance between the two screens.

Wheatstone's electrical method is preferable to either of the preceding. It is more accurate, and requires less bulky apparatus.

The use of electro-magnets in the above method introduces an error in the time required for the spring to come into action and press the pencil point against the surface of the revolving cylinder. This difficulty is removed by a method first suggested by Professor Henry, in 1843.

According to Henry's method, the electro-magnet is replaced by an induction coil. Each wire screen forms part of the circuit of the primary wire in an induction coil. On its rupture by the projectile, the induced current in the secondary coil causes a spark that punctures the paper on the surface of the revolving cylinder. This method of marking the time of rupture is now generally adopted.

Various forms of apparatus have been devised for measuring the minute interval of time required for a projectile to successively rupture the two wire screens. One class of such appliances will be found in what may be termed electro-ballistic apparatus. This form of appatus was devised by Navez, in 1849.

In electro-ballistic apparatus, the projectile, instead of striking the pendulum, and imparting to it a given velocity, simply releases a pendulum that is ready to fall under the influence of gravity. This release is effected when the projectile pierces the first wire screen. If, then, we can ascertain the exact position of the pendulum when the projectile pierces the second wire screen, and hence the distance it has fallen through, the time of flight between the wires can be readily calculated by determining the time required for the pendulum to fall freely through such distance.

The pendulum is held in position by an electro-magnet, in whose circuit the first screen is included. The passage of the ball through the first screen, therefore, permits the pendulum to begin its fall. On the passage of the ball through the second screen, the pendulum, or a detachable portion thereof, is arrested by the action of a powerful electro-magnet.

In Vignotti's Electro-Ballistic machine, a wire is placed over the gun so that the pendulum is released at the moment of firing. Marks are made on a paper placed on a graduated circle, by the sparks of induction coils, whose primaries are included in the circuit of the two wire screens. While the pendulum is falling, therefore, two marks are made on the paper, as the projectile successively ruptures the two

screens. The time required for the flight of the projectile between the two screens is determined by ascertaining the time required for the pendulum to fall from its zero point to each of the two marks. The difference of these times will be the time of the projectile's flight.

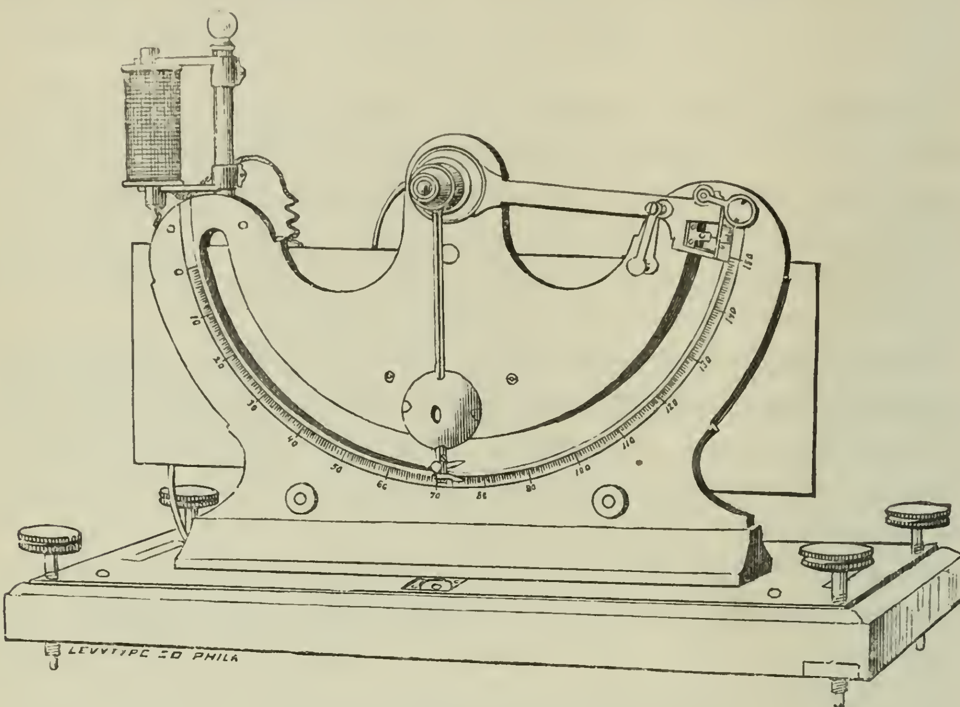


FIG. 1.—Vignotti's Apparatus.

This form of electro-ballistic apparatus is shown in Fig. 1. It consists of a graduated limb, provided with an annular slot through which a sheet of paper, moistened with a solution of potassium ferrocyanide, receives a spark from an induction coil. A brass plate is shown in the figure as placed back of the graduated limb and its annular slot. A pendulum swings before the limb with its axis suitably insulated therefrom. A fork is provided at the extreme end of the limb to catch the bob of the pendulum and limit its motion to a single swing. An electro-magnet, placed to the left of the limb is provided to hold the pendulum at the zero point of the graduated limb.

A wire placed over the muzzle of the gun is ruptured at the moment of firing, and breaking the current of this electro-magnet, permits the pendulum to fall.

One terminal each of the secondary wires of two Ruhmkorff coils is connected in series. The free terminal of one coil, the negative, is connected with the pendulum, and the free terminal of the other coil,

the positive, to the metallic plate back of the graduated limb. The primary of the first coil is inserted in the circuit of the first wire screen, and that of the second coil in the circuit of the second screen.

At the moment of firing, the pendulum is released. When the projectile pierces the first screen, the rupture of the primary of the first induction coil induces a current, which passing through the secondaries of both coils punctures the paper and produces therein a colored mark ; similarly, the rupture of the second screen produces a mark which shows the position of the pendulum at this moment.

From these data, as we have already explained, the time of flight of the ball may be readily calculated.

The Vignotti apparatus was improved at the Frankford Arsenal, under the direction of Colonel T. T. S. Laidley, Ordnance Corps, in the following particulars, viz.: the error of reading, due to the small arc described by the pendulum, was, to a great extent, eliminated by releasing the pendulum before firing. This was effected by means of a falling weight, which in its descent ruptured an electric circuit including an electro-magnet, which upheld the pendulum. The chemical paper was replaced by a soot-covered silver arc. These improvements were used on the apparatus shown at the exhibition.

In Benton's Electric Ballistic Pendulum, or Velocimeter, the successive ruptures of the wire screens permit the free fall of two pendulums suspended in front of a graduated circle, with their axes in a line passing through the centre of the circle and perpendicular to the plane of the arc ; or, in other words, two concentric pendulums, one swinging in front of the other, are held in a horizontal position at opposite extremities of the graduated arc, by the attraction of electro-magnets for a piece of soft iron attached to the lower extremity of each pendulum bob. These electro-magnets are included in the circuit of two separate batteries with the two wire screens or targets. As the projectile successively ruptures the targets, the pendulums are released and move over the graduated circle in opposite directions, and are caused to mechanically record the point of meeting on the graduated circle.

Benton's Electro-Ballistic Pendulum, or Velocimeter, is shown in Fig. 2. The semicircle is graduated 90° in each direction from the zero point, which is at the lowest point of the arc. The electro-magnets are placed at the extremities of the graduated circle in the positions shown. The bob of the outer pendulum is made adjustable so as to readily synchronize the two pendulums. At the lower extremity of

the inner pendulum is a movable point that projects towards the graduated circle. The outer pendulum is provided with a blunt steel point that strikes the movable point on the inner pendulum as the two pendulums pass each other, and thus makes a mark on a sheet of paper attached to the graduated circle.

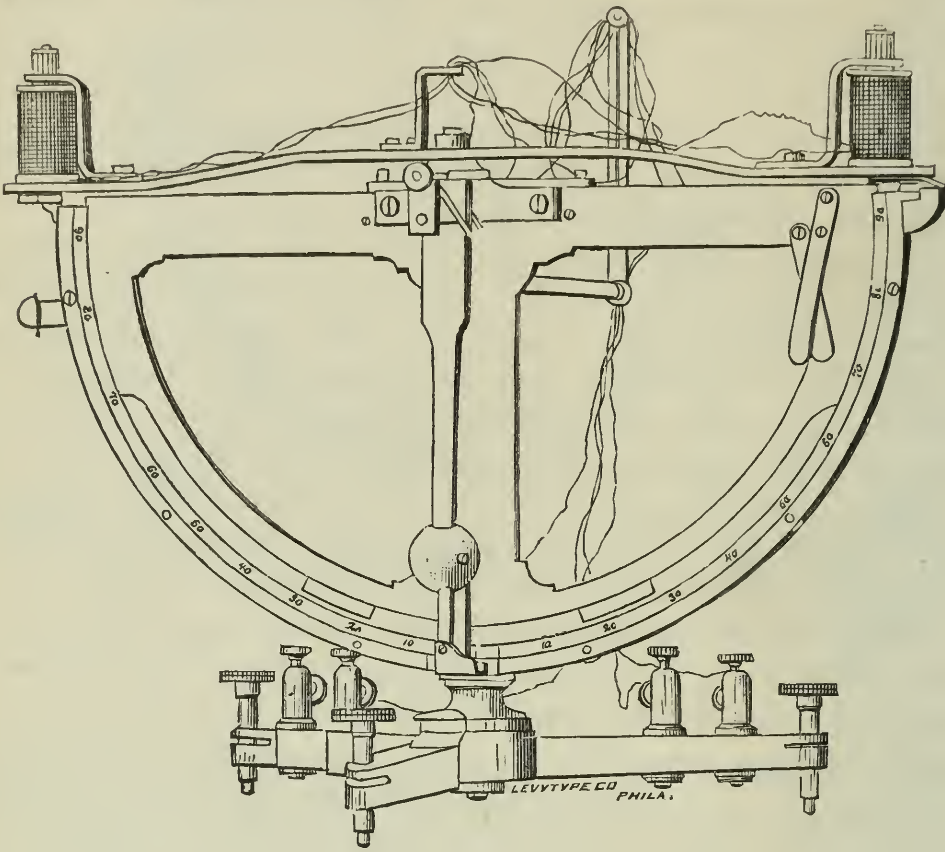


FIG 2.—Benton's Electro-Ballistic Pendulum.

Should both pendulums be simultaneously released, they will meet at the zero or lowest point of the arc, and will therefore make a mark on the paper at this point; but if one is released after the other, the difference in the times of release is readily determined from the position of the mark on the graduated scale.

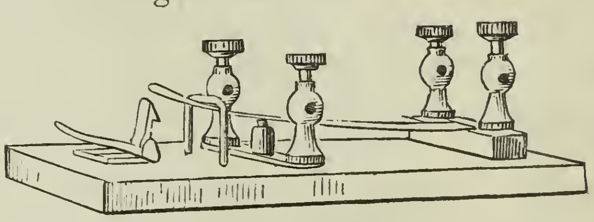

FIG. 3.—Key For Electro-Ballistic Pendulum.

In order to assure the same ease and consequent rapidity of release

of the two pendulums by the electro-magnets, it is necessary that the two batteries charging them be of exactly the same strength. This is ascertained by means of a special key shown in figure 3, which simultaneously breaks the circuits of the two batteries. If the two pendulums meet at the zero point of the graduated arc the two batteries are of the same strength.

As it is impracticable to maintain the two batteries at exactly the same strength, the electro-magnets are provided with movable, adjustable cores. In this manner an adjustment is readily obtained by means of which the recording of the meeting point of the two pendulums at the zero of the scale, when simultaneously released, is effected.

An improved device for the marking point is shown in Fig. 4.

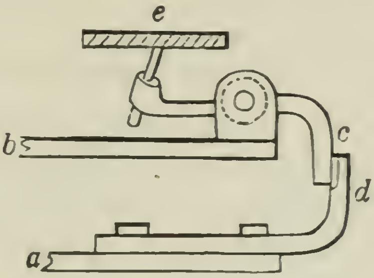


FIG. 4.—Marking Point of Benton's Velocimeter.

The bent arm *d*, is attached to the outer pendulum *a*. The lever *c*, is attached to the inner pendulum. As the two pendulums meet, the arm *d*, strikes the lever *c*, and pressing its marking point at the outer end against an ivory arc *e*, records thereon the point of meeting.

In the Schultz Chronoscope, a carefully tuned fork is caused to mark a waved line on the blackened surface of a revolving and sliding cylinder. This waved line serves as a scale of actual time; for, if the rate of the forks' vibration, that is the number of complete vibrations, or to and fro motions it makes in each second, be known, then clearly each wave on the blackened surface will have been made in a known time.

Suppose, for example, that Fig. 5 represents the waved or sinuous line traced on the blackened surface by the fork, then while the fork is making one complete swing, to and fro, it will trace the waved line between 0, and 1, or between 1, and 2. Consequently the cylinder has moved through the distance of the straight line between 0, and 1, while the fork has completed one to and fro motion. If therefore the fork

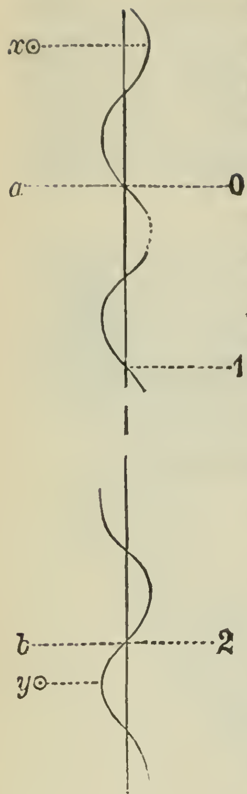


Fig. 5.—Sinuous- or Waved Line Traced on Blackened Surface by Forks.

makes 23 complete vibrations per second, the length of this line represents the $\frac{1}{23}$ part of a second of time. Or, if the fork make 512 vibrations per second, the line 01 would represent the $\frac{1}{512}$ part of a second. The use of tuning forks evidently permits very minute intervals of time to be readily and accurately measured. Their use also permits the velocity of a projectile to be measured at a sufficient number of points throughout its flight, to enable the law of its movements through the air to be studied, for it is evident from the extent of surface that can be given to the revolving cylinder that the number of targets, and their distance apart can be greatly varied.

The details of the Schultz Chronoscope are shown in Fig. 5. The revolving cylinder is seen at 1. The clockwork at 2, driven by the suspended weight, serves to impart to the cylinder a motion of rotation and translation. A handle attached to the driving axis serves to rotate and move the cylinder independently of the weight.

The tuning fork 4, is kept in constant vibration by the action of the electro-magnets placed as shown. A flexible point, attached to one tine of the fork can be caused to touch the surface of the cylinder when so desired. The interrupter 6, makes and breaks the circuits of the battery energizing the electro-magnets that keep the fork in constant vibration. This interrupter acts in the usual manner.

The mercury interrupter has been applied by the inventor as best serving to ensure constancy and continuousness of the forks' vibration. This interrupter is, however, extremely sensitive and difficult to adjust. Lieutenant Russel, of the Ordnance Corps, has disposed with the interrupter and caused the fork to do its own "rheotoming."

The well known sensitiveness of a tuning fork to hygrometric changes in the atmosphere necessitates, in the determination of very minute intervals, that its previously ascertained rate of vibration be discarded and its rate determined at the same time as the exact record. For this purpose the Froment pendulum accompanying the apparatus is not sufficiently delicate. Messrs. Bond, of Boston, have made for the Ordnance Corps a seconds break-circuit chronometer, which, by the

insulation of the breaking screw, gives a half-seconds break, entirely independent of the chronometer train.

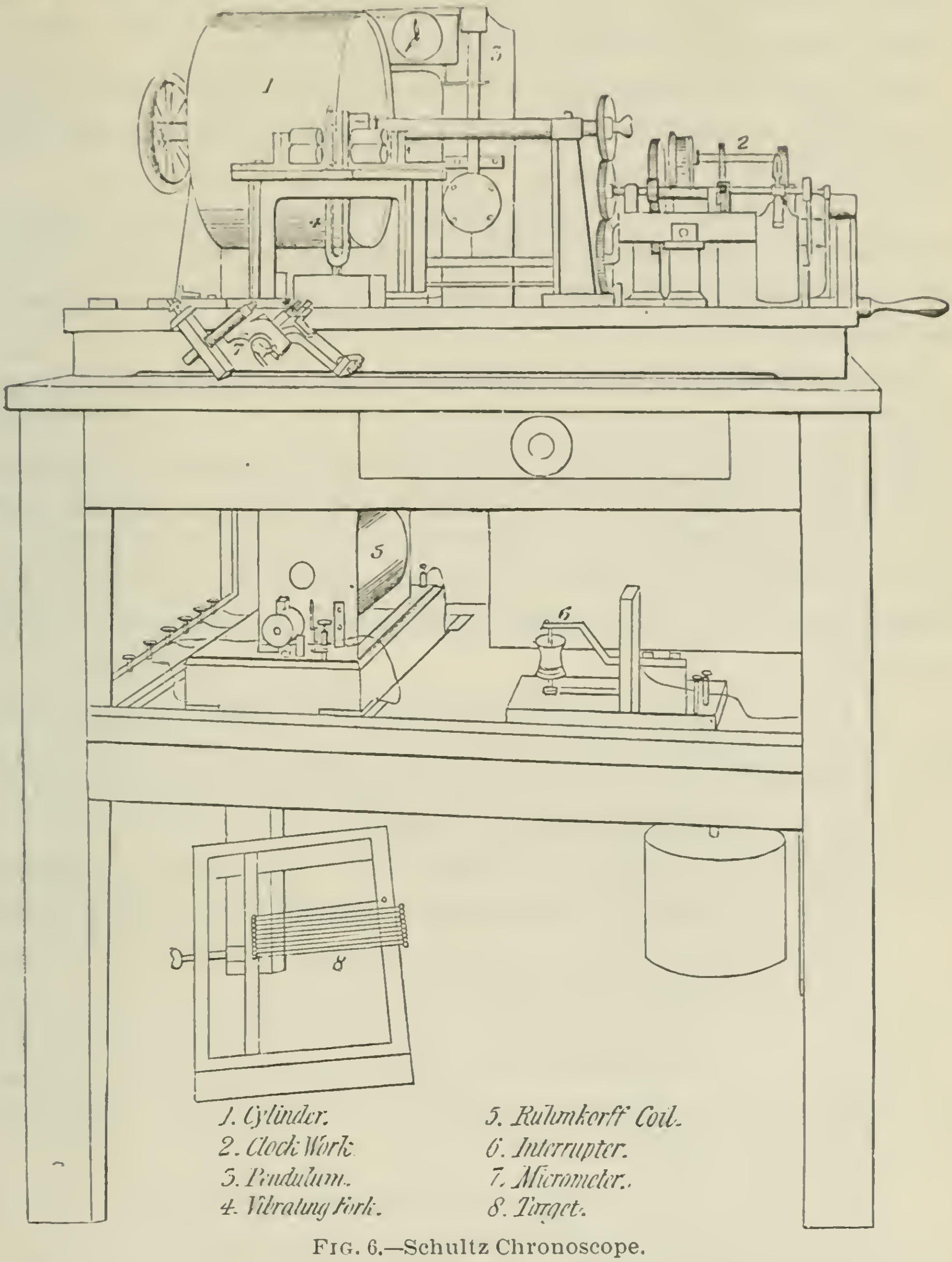


FIG. 6.—Schultz Chronoscope.

Michaelis has simultaneously applied two break-circuit chronometers, by means of two induction coils, for determining the true rate of the fork. The mean number of vibrations per second were

| | |
|---|---|
| By first chronometer | 248·2575 |
| By second " | 248·2276 |

The Ruhmkorff coil 5, has its primary included in the circuit of one of the wire targets, and, at the moment of its rupture, produces an induced current in the secondary that discharges as a spark and so makes a mark on the surface of the cylinder.

The general arrangement of the wire screws or targets is shown at 8. The projectile piercing the target at any point causes a break in the circuit in which it is included.

The micrometer at 7, is employed to divide one complete vibration or waved line on the surface of the cylinder into minute parts. By its use intervals of time as small as the $\frac{1}{500,000}$ part of a second can be easily read.

The pendulum 3, is of use to determine the exact rate of vibration of the fork.

Suppose now the cylinder be rotated and translated, and the ball successively rupturing two wire screens, the sparks from the Ruhmkorff coil produce markings at *x*, and F, on the cylinder alongside the sinuous or waved lines shown in Fig. 7. Then the rate of the fork being known the time of flight between the two targets is readily calculated.

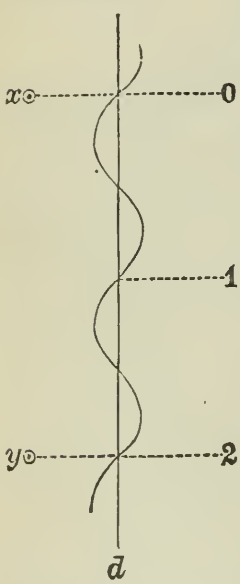


FIG. 7.—Curved line produced by the Schultz Chronoscope.

Should the markings made by the rupture of the targets not come exactly opposite the figures 0, 1, 2, etc., the micrometer is employed to ascertain the fractional part of the vibration.

It is an essential feature of the Schultz Chronoscope that the circuit ruptured by the projectile's passage through the first screen, must again be closed before the projectile arrives at the next screen. Various devices have been used to this end. Michaelis has applied with considerable success the simple and convenient expedient of an ordinary telegraphic relay.

In the Le Boulengé Chronograph, the time required by the ball to pass between the two screens, is deduced by observing the distance of the free fall of a heavy body during such time. This instrument is therefore different from the electro-ballistric pendulum apparatus already described, in that the movements of all pendulums is necessarily constrained by the fact of their suspension, or quoting Michaelis in his

description of this instrument, it "reduces the pendulum to its bob and allows it to fall freely."

In the Le Boulengé Chronograph two rods, one of which is longer than the other, are suspended by means of electro-magnets and permitted to fall freely when the circuits of their supporting electro-magnets are broken by the successive ruptures of the wire targets. The longer rod is included in the circuit of the first target and is therefore released first, so that while it is falling the shorter rod is released. A brief interval after falling, the shorter rod strikes a trigger which releases a spring and causes a knife to make an indentation in the larger rod. There is thus obtained the distance through which the longer rod has fallen freely while the ball is passing through the distance between the two screens, plus the time required by the instrument for its operation. Were both rods simultaneously released the longer rod would receive a mark near its lower end. The nearer the mark therefore to this end the greater the velocity of the projectile.

The Le Boulengé Chronograph may be used as a velocimeter, or as a micro-chronometer. In Fig. 8 the instrument is shown in position as a velocimeter.

The longer of the two rods is shown at *C*, and is called by the inventor the *chronometer*. It is a long cylindrical rod, enveloped by two zinc tubes, *D*, and *E*, called the *recorders*. The chronometer rod is held in position by the attraction of the electro-magnet *A*, on a spherical iron armature at its upper extremity. The coils of this electro-magnet are included in the circuit of the first wire target through which the ball passes.

The shorter rod, *E*, called the *registrar*, is placed as shown, and is supported by the attraction of the electro-magnet *B*, for its spherical iron armature, in a manner similar to the support of the longer or chronometer rod. The coils of the electro-magnet *B*, are included in the circuit of the second wire target through which the projectile passes. When the registrar rod falls, on the rupture of the second target, the free end of the lever *I*, is thereby depressed, the main spring is released, and the knife thrown against the falling chronometer rod indents the upper recorder. A hollow tube, *L*, intended for the reception of the registrar rod *F*, is adjusted so that the rod falls without touching it.

The details of the indenting apparatus are shown in Fig. 10. The lever *I*, pivoted at *T*, releases the main spring *H*, and permits the circular knife *G*, to indent the upper recorder.

In order to insure the free fall of the rods the electro-magnets are preferably weak, though of course strong enough to support the rods

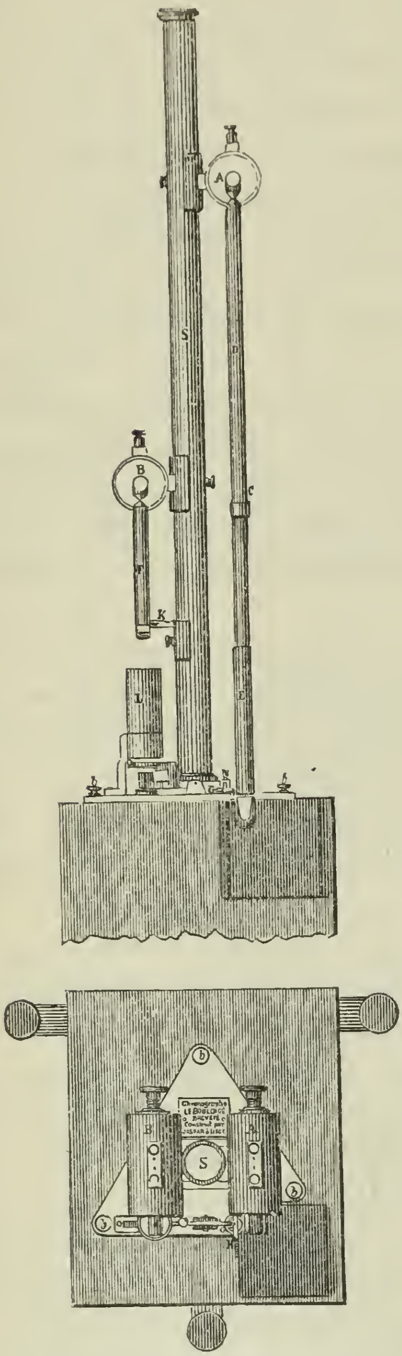

FIG. 8.—Le Boulengé Chronograph in Position as a Velocimeter.

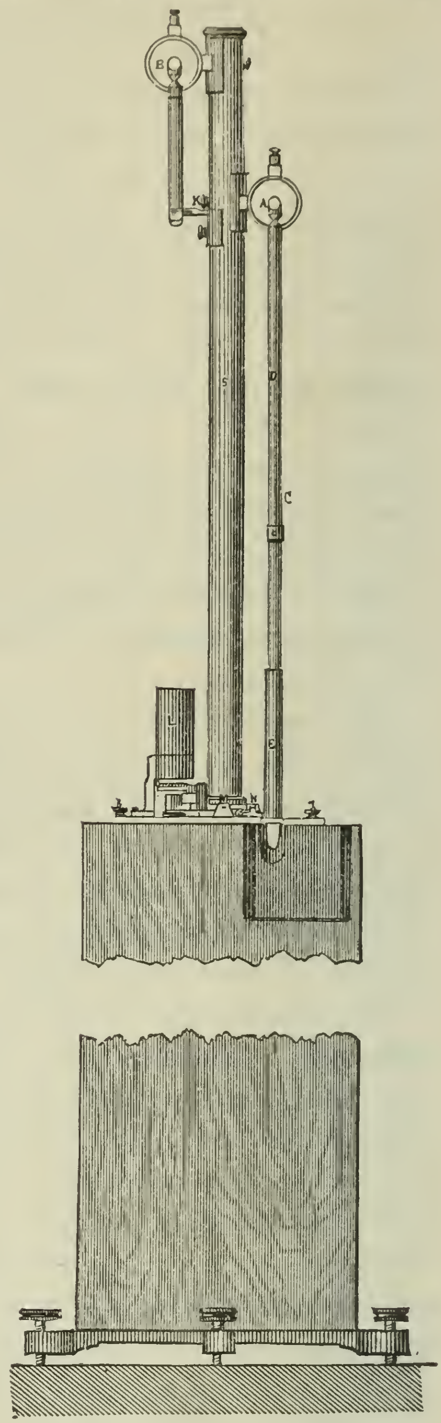

FIG. 9.—The Le Boulengé Chronograph in position for use as a micro-chronometer.

with certainty. In this manner the errors due to the residual mag-

netism, which result in a short interval, elapsing between the fall of the rods and the rupture of the screws, is diminished.

When the Le Boulengé Chronograph is employed as a velocimeter, as in Fig. 8. and the distance between the two wire targets is comparatively great, the chronometer rod receives an indentation near the top, or at the moment of time when it is falling with its maximum velocity, and therefore minute differences in time, are recorded by comparatively great differences in height. When, however, the interval is exceedingly small, this arrangement of the apparatus has the disadvantage that the record of the fall of the registrar rod is received by the chronometer rod near its lower end, where the velocity of fall is small. A different arrangement is therefore desirable when it is wished to employ the apparatus as a micro-chronometer. This is effected by a very simple readjustment of the instrument. This readjustment is shown in Fig. 9. where the instrument is represented in position for use as micro-chronometer.

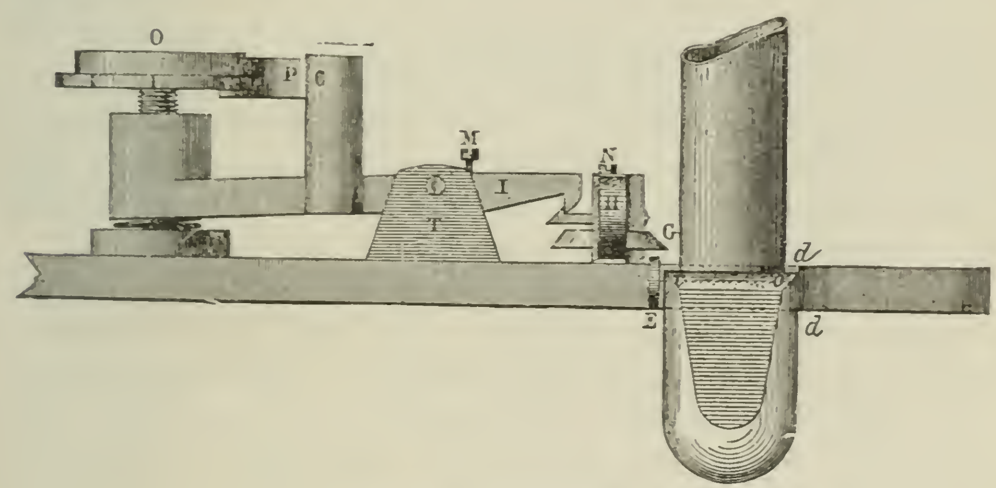


Fig. 10.—Indenting Apparatus.

In this figure it will be observed that the registrar rod with its stop and supporting electro-magnet *B*, are removed to the upper part of the instrument. They are now included in the circuit of the wire target that is broken first. The longer rod therefore begins to fall after the first has been falling and when *B*, strikes the lever *I*, at the lower part of the apparatus, it causes the indent to be made on the upper recorder, or when the longer rod has its greatest velocity. By means of this ingenious modification, very minute intervals of time are easily and accurately measured.

In the preparation of the above descriptions the author has consulted

the work by Benét, on "Electro-Ballistic machines and the Schultz Chronoscope," and the work by Michaelis, on "The Le Boulengé Chronograph." He is indebted to these works for the accompanying cuts.

CENTRAL HIGH SCHOOL,
PHILADELPHIA, Nov. 29, 1884.

## CONTRIBUTIONS TO OUR KNOWLEDGE OF SEWAGE.

BY WM. RIPLEY NICHOLS AND C. R. ALLEN.

In the year 1872, one of us had occasion to report* the results of the chemical examination of a considerable number of samples of the sewage of Boston and of Worcester, Mass. The examinations then made included the determination of the nitrogen existing as ammonia or in the form of ammoniacal salts (tabulated as free ammonia), and of the nitrogen which was given off as ammonia by treatment with an alkaline solution of permanganate of potash, according to the well-known method of Wanklyn. As indicating the total amount of organic nitrogen, this last determination—that of the so-called "albuminoid ammonia"—was felt at the time to be inadequate, but under the then existing circumstances it was the best that could be done.

When Kjeldahl's process for the determination of the total nitrogen in organic substances was published a few years ago,† it suggested itself at once that the method might possibly be conveniently applied to the analysis of sewage. Circumstances have prevented, until recently, the carrying out of this idea; meanwhile, the process has found extensive application, especially in agricultural laboratories, and has been used in the analysis of certain kinds of fertilizers. It is possible that it may have elsewhere been applied to the examination of sewage; if so, we have failed to meet with notice of such application, which we find to be quite practicable and to give satisfactory results.

In order to familarize ourselves with the process and, at the same time, to become satisfied of its substantial accuracy, determinations of

* Fourth Annual Report of the State Board of Health of Massachusetts. Boston, 1873. Pp. 65-81.

† *Fresenius Zeitschrift*, xxii (1883), p. 366; *Chemical News*, xlviii (1883), p. 101.

the total nitrogen were made in sulph-urea, in dried and powdered horse dung, and in dried and powdered human excrement, the amount of nitrogen being checked either by theory or by an absolute determination according to Dumas' method. The results were as follows:

| | I. Kjeldahl's method. | II. Dumas' method. | III. Theory. |
|---|---|---|---|
| Sulph-urea | 36·89 per cent. | ...... | 36·84 |
| Horse dung. 1 | 3·16 " | 3·28 | ...... |
| " 2 | 3·12 " | ...... | ...... |
| Excrement | 6·20 " | 6·08 | ...... |

In order to satisfy ourselves as to the constancy of the results obtained in a number of determinations made on the same sample of actual sewage, a sample was procured and analyzed with the following results:

*Organic Nitrogen Expressed as Parts in* 100,000.

| Kjeldahl (after deducting nitrogen as free ammonia). | Dumas. |
|---|---|
| 3·75 | 3·66 |
| 3·50 | ...... |
| 3·75 | ...... |
| 3·70 | ...... |
| 3·75 | ...... |
| 3·75 | ...... |
| 3·80 | ...... |

It thus appears that the process gives uniform results, and that these results are sufficiently accurate for the purpose. It has the advantage of requiring only the ordinary apparatus used in water analysis, as generally conducted in this country, and of avoiding a dry combustion, which, in the simplest form, is more or less troublesome, especially where a liquid has to be evaporated, and the solid residue transferred from the evaporating dish.

There is little doubt that the coming decade will see in this country a considerable application of the method of disposing of sewage by irrigation, and it seems to us that Kjeldahl's process will afford a ready

means of determining the amount of that important constituent—the combined nitrogen. The process, as we have used it with sewage is as follows:

From 25 to 50 cubic centimeters of sewage are introduced into a small flask, preferably flat bottomed, made acid with sulphuric acid and evaporated to dryness on a water-bath. This is best and most rapidly accomplished by drawing through the flask a somewhat rapid current of air which has been freed from moisture and ammonia by bubbling through strong sulphuric acid. We have satisfied ourselves that the loss of "free ammonia" by this treatment is inappreciable so that the residue contains the total combined nitrogen* of the sewage. This residue is treated in the flask with 5 cubic centimeters of fuming sulphuric acid which is run in from a glass-stoppered burette. The flask is placed on a piece of wire-gauze over a small gas-flame and heated until a light yellowish-brown liquid is obtained. With sewage this result is sometimes reached in half an hour; usually from one to two hours are required. Permanganate of potash is then added to complete the oxidation, a few crystals being sufficient.†

The contents of the flask are then washed into the distilling apparatus with about 500 cc. of pure distilled water, enough caustic potash is added to give an alkaline reaction, and the nitrogen, which is now all in the form of ammonia, is distilled off in the usual way. The distillate is made up to 250 cc. and aliquot portions are nesslerized as in water analysis. As the sulphuric acid usually contains a trace of nitrogenous compounds, a blank experiment determines a slight correction to be applied.

The process as just given may be modified by evaporating the sewage without first acidulating with sulphuric acid. The evaporated water may be condensed and the free ammonia determined therein and an approximate determination of the total solids may be made by using a tared flask. We prefer, however, to proceed as indicated above and to make a separate determination of free ammonia, with which may be coupled, if desired, a determination of the so-called albuminoid ammonia.

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* The nitrogen which exists in the sewage as nitrites and nitrates is too small to be of practical importance although there is usually a trace.

† For fuller details, see Kjeldahl's original paper, referred to above.

### BOSTON SEWAGE.

Since the examinations of sewage made in 1872, the Boston system of sewerage has undergone an entire change. Instead of being discharged from short sewers emptying at intervals along the water-front, the sewage is now collected into one encircling sewer, carried by means of a tunnel to Moon Island and allowed to flow into the outer harbor on an ebb tide.

We have examined a number of samples taken from the pumping station at City Point where the sewage is lifted in order that it may flow through the tunnel to Moon Island. The sewage was received as a rule in a fresh condition; the heavier suspended particles were allowed to subside and no attempt was made to determine their amount. In fact, the determination of suspended matters in small samples is of little value and a more practical idea of their amount could be obtained on a large scale by estimating the amount deposited in the settling-tanks. The following table contains the results of the examination of various samples of sewage from the pumping station. It will be noticed that the samples taken at different times vary very much from each other. The large amount of total solids and chlorine are said to be due to the fact that a considerable quantity of sea-water is used in certain manufactories for cooling purposes and to the infiltration of salt water into the sewers which are below the tide level.

### NITROGEN AS UREA.

The rapidity with which urea is converted into carbonate of ammonia and water in the presence of the urea ferment which is probably always present in sewage, would prevent its existence in stale sewage, but as the Boston sewage reaches the point from which our samples were taken in a fresh condition, we might expect to discover some of this substance still unchanged.

The evidence that urea was present in several samples which were tested is as follows: Two portions of 50 cc. each were boiled in small flasks to expel the free ammonia and to kill any of the ferment present, and the necks of the flasks then stopped with cotton wool. When the contents had become cool one of the flasks was infected by dipping a glass rod first into a fermenting solution of urea, or into stale sewage and then into the boiled sample. The two samples were allowed to stand side by side for several days, and then examined for free

## *Examination of Boston Sewage.*

[Results expressed in parts in 100,000.]

| Number. | Date of Collection. | Ammonia | Albuminoid Ammonia | Total Nitrogen, reckoned as Nitrogen. | Total Nitrogen, reckoned as Ammonia | Total Solids. | Chlorine. | Chlorine reckoned as common salt. | Phosphoric Acid. ($P_2O_5$.) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1885. May 12, 7.30 P. M. | 2·80 | 0·27 | 2·80 | 3·40 | 592 | 275 | 453 | 0·480 |
| 2 | 13, 8.20 A. M. | 3·18 | 0·14 | 3·46 | 4·20 | 518 | 258 | 425 | 0·096 |
| 3 | 13, 7.20 P. M. | 3·42 | 1·15 | 5·76 | 7·00 | 254 | 82 | 135 | 0·6[illegible]2 |
| 4 | 14, 7.20 A. M. | 1·32 | 0·35 | 1·81 | 2·20 | 570 | 247 | 407 | 0·701 |
| 5* | 15, 1.00 A. M | 1·29 | 0·87 | 4·63 | 5·62 | 482 | 133 | 219 | 1·343 |
| 6* | 15, 8.15 A. M. | 1·59 | 0·25 | 6·00 | 7·30 | 416 | 191 | 320 | 0·512 |
| 7 | 15, 4.00 P. M. | 3·08 | 0·55 | 3.76 | 4·57 | 358 | 145 | 239 | 0·192 |
| 8 | 16, 7.30 A. M. | 0·95 | 0·55 | 2·14 | 2·60 | 630 | 311 | 513 | 0·288 |
| 9 | 17, 4.25 P. M. | 5·68 | 5·96 | 14·53 | 17·65 | 551 | 215 | 354 | 7·035 |
| 10 | 18, 8.00 A. M. | 6·23 | 5·81 | 13·82 | 16·78 | 528 | ? | ? | 6·490 |
| 11 | 24, 7.50 P. M. | 11·94 | 3·32 | 17·15 | 20·82 | 178 | 59 | 97 | 3·325 |
| 12 | 23, 12.40 A. M. | ? | 2·62 | 4·32 | 5·30 | 378 | 178 | 293 | 0·992 |
| 13 | 26, 12 hour day average† | 5·71 | 4·22 | 11·32 | 13·75 | 460 | 177 | 292 | 4·893 |
| 14 | 27, 12 " " " † | 5·71 | 3·31 | 9·55 | 11·60 | 610 | 288 | 475 | 6·188 |
| 15 | 28–29, 24 " average‡ | 3·13 | 5·49 | 9·82 | 11·93 | 588 | 240 | 396 | 4·702 |
| | 1872. Average of 33 day samples§ | 2·72 | 0·73 | ........ | ........ | 59 | 19 | 31 | 1·69‖ |
| | " " 4 night " | 1·33 | 0·23 | ........ | ........ | 17 | 4·5 | 7·4 | ........ |

* Samples 5 and 6 contained a good deal of storm water. † Samples taken every four hours. ‡ Samples taken every two hours.
§ Samples from sewers near the water front, which evidently contained much sea-water, were not included in these averages.
‖ Average of 19 samples.

ammonia is a similar fashion. In one case the flask which had not been impregnated was free from ammonia, generally, however, a small amount of ammonia had developed itself,* in all cases the impregnated flasks showed a much greater amount of ammonia than was contained in the companion flasks. This certainly points to the presence of urea or some similar fermentable nitrogenous compound in the sewage as it reaches City Point.

In conclusion we desire to acknowledge our indebtedness to the Department of Improved Sewage for facilities in collecting samples, especially to Mr. Barnes, at Chester Park, and to Mr. M. H. Holmes, at the pumping station.

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## LIST OF BOOKS

### ADDED TO THE LIBRARY TO MARCH 1, 1885.

Richmond, Indiana. Report of Water Supply. 1880. From J. R. Wirst, M. D.

Rolker, Charles M. Note on a Fire-Bulkhead. 1884. From American Institute Mining Engineers.

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Use of the Optical Telegraph.—The optical telegraph which has been successfully established between the Isle of Bourbon and Mauritius is likely to prove of great value to commerce by its storm warnings. Bourbon has only open bays where ships run great risks during cyclones if they do not weigh anchor soon enough to flee before the tempest. Mauritius which has an excellent harbor, is situated on the route which the cyclone traverses before reaching Bourbon. By the optic telegraph information can be sent to the latter island in time to enable all the vessels to take such precautions as are needful.—*Les Mondes*, Sept. 11, 1884. C.

# JOURNAL

OF THE

# FRANKLIN INSTITUTE

OF THE STATE OF PENNSYLVANIA,

FOR THE PROMOTION OF THE MECHANIC ARTS.

VOL. CXX. SEPTEMBER, 1885. No. 3.



## ON THE ANCIENT ART OF PAINTING IN ENCAUSTIC.

BY JOHN SARTAIN.

[*Abstract of a Lecture delivered before the* FRANKLIN INSTITUTE, *April 9, 1885.*]

An opinion has prevailed, for a long time past, that the painters of antiquity never attained a high degree of skill in their art, and that the stories told by the writers, who were contemporary with the most celebrated artists of Greece, greatly exaggerated the real merit of their productions.

This disparaging judgment was based on the character of the numerous wall paintings that are to be seen in the remains of Pompeii, Herculaneum and Rome. But these pictures are only the work of mere decorators, and are wrought by a process wholly different from that practised by the great Greek artists, who did not paint on walls. They painted what were known as tablet pictures, that could be handled, and moved from place to place, like the easel pictures of the moderns. They were not in oils, nor in what the Italians term fresco, nor were they in distemper. They were in encaustic, which means burnt in.

The Greeks claim to have invented this method of painting; but there is good reason for believing that they learned it from

the Egyptians, who wrought in this same manner, as is proved by the remains of their work found in the tombs at Bab el-Malook, near Thebes. In Greece, the practice began before the time of Pericles, and continued into the Græco-Roman period, after which it became a lost art, when, about the middle of the last century, attention was drawn to it by the book I now show you, written by Count Caylus, who derived what knowledge he possessed from the writings of Pliny.

The examples of encaustic painting, as practised by the celebrated Greek artists, have disappeared, and those that may have survived still lie buried under the accumulated débris of ruined buildings in Greece or Italy, excepting only the two of which copies will be shown you on the screen, greatly enlarged beyond the natural size, of course.

You are all familiar with the numerous anecdotes told concerning Apelles, Zeuxis, Protogenes, Apollodorus, Timomachus, and other prominent artists, especially of those who flourished in the time of Alexander of Macedon, or about three and a-half centuries before the Christian era. One of these relates, that Apelles, in despair at his ill success in imitating the foam around a horse's mouth, flung his brush at it, and accident produced admirably just the effect he desired. This oft-repeated story is very pretty, but, like many other stories, lacks a foundation in fact. *Apelles did not paint with a brush, but with a hot iron tool, called a stylus.* It was pointed at one end for drawing outlines, and broad at the other end for laying on the paints. It had to be heated for use, because the vehicles in which the colors were ground consisted of resin and wax, in the proportions of two-thirds resin to one of wax. After the picture was finished, it was exposed to fire and burnt in. The effect produced is described as resembling enamel, but with a subdued gloss.

In the Pandects of Justinian, materials for encaustic painting are specified in the legacy of a painter, and among them the peculiar "*Cauteria*," which is the same as the "*Bas Ferrium*" of Pliny and Vitruvius, namely, charcoal braziers for heating the stylus and colors, and for burning in the picture.

As I have said, there are as yet but two ancient encaustic pictures known. The first discovered is what is designated as the "Muse of Cortona," so named from the city in which it is preserved, and near which it was found. The enlarged image thrown upon

CŒRIS PINGERE, AC PICTURAM INURERE, ETC.

—*Plin. Hist. Nat. Lib. xxxv, Cap. xi.*

[Frontispiece to Count Caylus' book on "Ancient Encaustic Painting," published in 1755.]

the screen is an exact copy of the original picture, except in size and the absence of color. The painting represents the figure a little smaller than life. The manner of its discovery and its subsequent vicissitudes are remarkable, and happened thus: A farmer, while ploughing in a field between Centoja and Montepulciano; turned up a large slab of slate, on which he perceived what appeared to him a picture. On cleaning it, he regarded it as a representation of the Madonna, and he placed it on a wall of his dwelling with a lighted taper in front of it. A priest, who came to administer to his sick and dying wife, told him it was a vile, heathen thing that had had a baneful effect, and that he ought to throw it out. He said if she had done harm he would do better by putting her in purgatory; accordingly, he fitted the picture to serve as the door of his oven. From this perilous ordeal it was rescued in 1735, three years after its discovery, by the Chevalier Tommaso Thommasi, the lord of the domain, and it remained in possession of the family until 1851, when Madame Louise Bartolotti Tommasi presented it to the Tuscan Academy of Cortona, which has placed it in its museum. The picture shows no sign of having suffered in the least from exposure to the fire of the oven, owing, no doubt, to the fact that, being an encaustic painting, the finishing of the work originally was by firing.

Many important discoveries of antique treasures have been made, as remarkable as this of the Cortona Muse Polyhymnia. For example, the one only copy of Tacitus that escaped the general destruction of the Roman libraries was found in a Westphalian monastery. Quintilian was picked out from a heap of rubbish that filled an old coffer. Part of Livy was found between the leaves of an old bible, and a missing page of it was found stretched on a battledore. Cicero's important treatise, "*De Republica*," was discovered concealed beneath some monastic writing. There is no time to extend this catalogue.

Mr. Holman will now show you, on the screen, a sketch of the city where the picture of the Muse is preserved, Cortona, as seen from the foot of the hill on which it stands A large portion of the original Etruscan wall still remains and nearly surrounds the city. When it was built is not known, but certainly not less than 3,000 years ago.

ON STEEL BY JOHN SARTAIN FROM THE ORIGINAL ANTIQUE PAINTING AT CORTONA, ITALY,
IN THE POSSESSION OF THE MUNICIPALITY.

THE MUSE OF CORTONA.

The next sketch is taken from alongside this Etruscan wall, looking down on the Lake Thrasymene, near which, as you will remember, the Carthagenians, under Hannibal, defeated the Romans in battle. On the extremity of the tongue of land seen protruding into the lake stands the city of Castiglione del Lago.

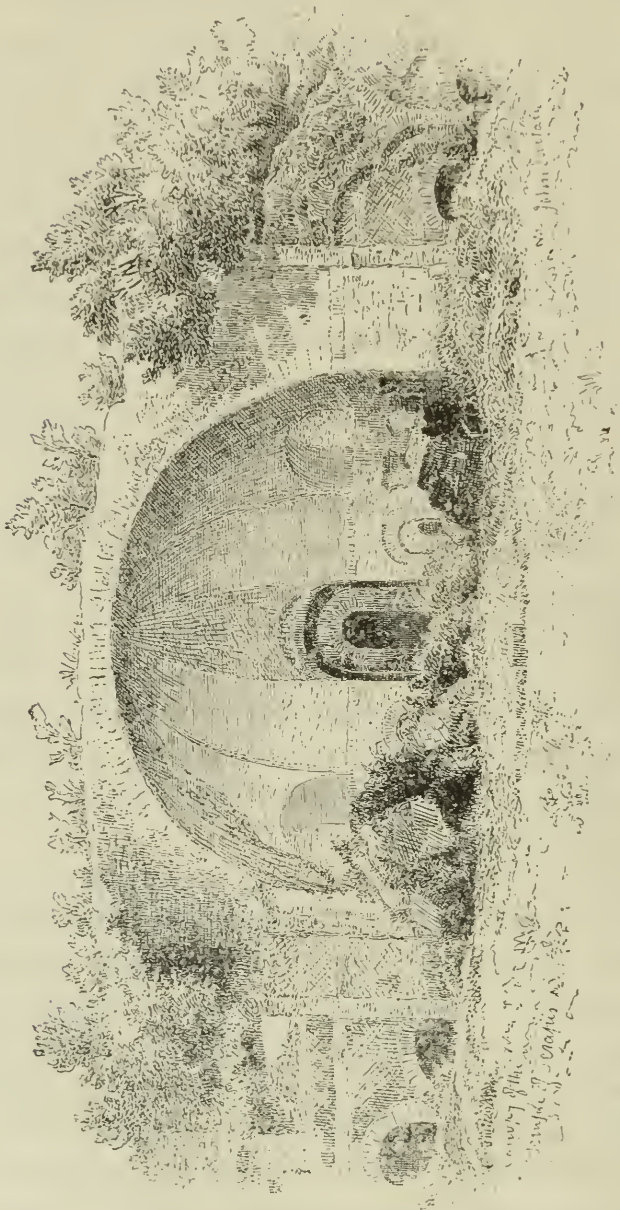
Cortona was one of the confederated cities of ancient Etruria, and, of course, Etruscan relics found beneath the earth's surface are numerous. Mr. Holman will now show you on the screen a tomb or monument that stands part of the way down the slope of the hill. It is circular, and so massive in construction, that the ruin you see, could only have been wrought intentionally, and by means of the most powerful appliances, the motive being probably superstition. It was roofed in by enormous single stones, spanning the apartment across from wall to wall, and four recesses in the interior of the wall shows where sarcophagi had been placed.

We will now leave Cortona and its pictured Muse to look on the other more important encaustic picture of Cleopatra, which is preserved at Sorrento, near Naples, and belongs to the Baron de Benneval, in whose possession it has remained for the past twenty-five years. It was found at Hadrian's villa, near Tivoli, in the year 1818, under the ruins of the Temple of Serapis. Of the Muse of Cortona nothing is known, except that it is unquestionably Greek, but concerning the Cleopatra we may arrive at a tolerably well-connected history and fix the date of its production at twenty-nine years before the Christian era.

Thirty years before Christ, the fleet of Augustus Cæsar gained the decisive victory at Actium over that of Egypt led by Anthony and Cleopatra. The queen foresaw the inevitable fate that awaited her of being paraded through the streets of Rome to adorn the triumph of the conqueror. To escape this mortifying humiliation she committed suicide, and Augustus, being thus deprived of the presence of Cleopatra herself, ordered a picture of her painted to serve as her representative. It is recorded that this was borne on a car or litter along with many valuable objects of Egyptian interest taken from the monument in which she died, and which she had collected there. After the picture had served the purpose for which it was painted, he presented it to the Temple of Saturn at Rome

Some 140 years later, the Emperor Hadrian caused to be removed from Rome a large quantity of the choicest art treasures

of the city, in order to enrich and adorn the vast villa he had built near Tivoli (the ancient Tibur) and, no doubt, the Cleopatra picture was among the objects thus removed, and it found an appropriate resting-place in the Temple of the Egyptian God



CANOPY OF THE TEMPLE OF SERAPIS, HADRIAN'S VILLA, UNDER WHICH THE CLEOPATRA WAS FOUND IN 1818.

Serapis, under the ruins of which the picture before you was found. It is well known how many of the most beautiful and celebrated statues that enrich the national museums of Europe, were dug from the ruins of this wonderful villa, as, for example, the "Venus di Medeci," the "Antinous," and other important works.

The history of the Cleopatra picture since its discovery is briefly this: Dr. Micheli, the antiquary, and his brother, who were associated in the ownership, endeavored to obtain a safe and permanent repository for their treasure in the famous Florentine Museum, through a sale to the Grand Duke of Tuscany, but the large price demanded could not be spared from the depleted treasury at a time so little removed from the political convulsions and great wars of the first French empire. Some years later the affairs of the Micheli brothers necessitated their borrowing money on the picture from some Jews, soon after which they both died. The charges went on increasing with time, and the heirs finding themselves unable to redeem it, sold it to an acquaintance of the Baron de Benneval, who liberated it from the hands of the usurers at great sacrifice. He afterwards sold it to the present owner in 1860.

The picture has given rise to voluminous literary research. Some writers claim that it is the work of the famous Byzantine artist, Timomakos, who was the author of two pictures purchased by Julius Cæsar, for a sum equivalent to $350,000. One of these was of "Medea," and the other "Ajax," the former one unfinished. He had them exposed to public view in the portico of the temple of Venus Genetrix, and afterwards presented them to the temple as votive offerings. The Greek pictures in encaustic commanded enormous prices, and cities contended with each other for their possession. The one painted by Apelles, for the City of Cos, of "Anadyomene, or Venus Rising from the Sea," was received by Augustus Cæsar 300 years later as the equivalent of $100,000, notwithstanding an irreparable injury the picture had sustained in the lower part of the figure. This work he caused to be placed in the temple of Julius Cæsar.

Some writers claim that the Baron de Benneval's picture is a *portrait* of the Egyptian queen, but it should be borne in mind that it was not painted until after her death, and then simply to represent her in the Roman triumph. It seems to be agreed that she was not so remarkable for beauty as for her accomplishments, and fascinating manners. That the end of her nose drooped below the nostrils. It is difficult to draw a comparison between the Sorrento picture, being a front face, and other accepted profile representations of her on coins, and also of the colossal one of her in the character of Isis, cut in the wall of the Pronaos to the Temple

of Dendera. I show you a portion of the latter, and also a coin in the British Museum. I did not know in time that there is a Cleopatra coin in the collection at our Philadelphia Mint, but is not easily seen because in a very obscure light.

CLEOPATRA COIN IN BRITISH MUSEUM.

The splendor of her costume in the picture before you, her jewels and the crown on her head, all correspond with the known facts attending her death. Plutarch and Dio Cassius agree in the statement that "she gave herself to death in full royal array." After she had deceived Octavius and his envoys as to her intentions, "she put on her most beautiful dress and ordered everything in the most sumptuous manner." "They found her dead, lying upon a golden couch in royal array. Of her women, one whose name was Iras, lay dying at her feet, but the other, Charmion, although she already tottered and her head swam, was engaged in setting right the diadem on the head of the queen." "There was neither swelling of the body nor any sign of poison apparent."

It is known that Cleopatra had watched experiments of the effect of adder poison on condemned criminals. "She saw that, almost alone, the bite of the adder produced a death-like sleep without convulsion or cry of pain, that the subject was to a certain degree paralyzed, having a slight perspiration on the face and a weakening of the mind, and could only be aroused with extreme difficulty, like those in a very profound slumber."

There cannot be a doubt that the death of the queen was caused by the bite of the poisonous reptile "and the Emperor himself appears to have entertained this opinion, for at his triumph a picture of Cleopatra with a firmly-biting snake was carried." Certain it is that a picture like the one here shown you was painted at that time for the above-named purpose by command of Octavius, so that she might, in a manner, be seen in his triumph along with

his other prisoners of war. The Sorrento picture corresponds with the documentary records, showing the same features that are mentioned in the accounts of Octavius' picture that was carried in the triumph on the litter with other valuable objects of Egyptian booty found in the chamber of death. All things impartially considered, the Baron is justified in pronouncing the pictures identical.

You have seen on the screen the place where the picture was found, you will now see a view of the building in which it is preserved. It is the villa of the Baron de Benneval on the Piano di Sorrento, but a short distance removed from Sorrento proper, which borders the steep cliffs that inclose one side of the beautiful bay of Naples, and here the poet Torquato Tasso first saw the light of day.

I think that the only thing remaining to be spoken of in connection with this subject of encaustic painting, as practised by the ancient Greeks, is the pigments they used, and from whence obtained. My statement must be brief, because the space of time allotted is short, and I fear to tire your patience on so dry a subject.

First as to the vehicles. From Pliny and Vitruvius, we learn that among the various tree resins, that of the Pistacia Lentiscus was used. From Rosellini, that the Egyptians used wax and naphtha. Through Pliny and Dioscoridės, that a mixture of wax and resin was used in ship painting. Geiger found that wax and resin were used in Epyptian painting, and Knixim defines the proportions as agreeing with what the Marquis Ridolfi found in the paint he analyzed from the picture of Cleopatra, namely, two-thirds resin to one-third wax.

In 1851, a quantity of painting materials was found at Pompeii, in the Street of Stabia. Beside colors, were pieces of asphaltum and resin, a mixture of asphaltum and pitch, and a great piece of bright yellow ochre that contained pieces of resin. Near St. Medard des Près were found, in the tomb of a Gallic Roman female artist, in addition to colors and paint boxes, a glass vessel with a piece of resin, which Chevreul takes to be either pine or fir, or pitch resin; also, in one phial, wax; in another, wax mixed with resin; and in a third, a black color mixed with wax and oil.

Concerning the pigments, Pliny says: "For encaustic painting, they used purple-red, indigo, Egyptian blue, white lime earth

CLEOPATRA, FROM THE CARVING ON THE PRONAOS OF THE TEMPLE AT DENDERA, EGYPT.

(calcareous earth), arsenic yellow, appianum and lead white." Migliarini says: "The white of Egyptian painting is not lead white, but a very fine and pure calcareous earth. Sir Humphry Davy says: "The white (in the colors of the baths of Titus, and in the Aldobrandini wedding) is chalk, or a fine clay. Among Egyptian colors is an especially well preserved white, supposed to be the parœtonium of Vitruvius and Pliny, so-called after the place where it was found, near the city of that name, the capital of the Lybian Nomos.

Of the yellows, Migliarini says: "The yellow (of Angelelli's Egyptian color experiments) is iron ochre" (the Latin *ocria*, or *sil*), the best quality of which, according to Pliny, was found in Attica. Davy says: "The yellow is ochre sometimes mixed with oxide of lead and chalk." Ridolfi found that the gold of the jewels of the Sorrento Cleopatra was composed of yellow ochre.

Concerning the reds, Migliarni found "a red of a very beautiful tone to be tritoxide of iron." Vitruvius places the Egyptian next to the best, which is that of Sinope. But Pliny asserts that the Egyptian and the African are the best for painters. Davy found three kinds of red, a bright red approaching orange, consisting of vermilion, or red oxide of lead, a dark red and a purple red, both composed of iron ochre, also cinnabar. Ridolfi says: "Tritoxide of iron made the red of the Cleopatra mantle, and vermilion was used in the folds."

The blue, of which Theophrastus mentions three qualities—the Egyptian, the Scythian, and the Cyprian—was invented in Egypt, and thence imported to Puteoli. According to Vitruvius, it was prepared by burning a mixture of saltpetre, sand, and chippings of copper. The eminent chemist, Sir Humphry Davy, found in this same blue (which he regards as the Egyptian) fifteen parts of the carbonate of soda, twenty parts of siliceous stone, and three parts filings of copper. But in nine ancient blue glasses of different origin, he always found cobalt instead of copper, and he is of opinion that Theophrastus confounded the cobalt with copper.

Finally, concerning the green, Davy says: "One green approaches olive green, and is common Veronese green earth. Another is like carbonate of copper, mixed with chalk. A third consists of a green copper composition with blue copper frit." Chaptel says: "The green is a mixture of green earth;" and

Ridolfi found the green of the background of the Cleopatra picture to be "a mixture of green earth and carbonate of copper."

We will conclude this brief statement of an interesting subject, by quoting the opinion of Sir Humphry Davy, that the color scale of the ancients was not inferior in scope to that of the great painters of the sixteenth century. They possessed vermilion, red arsenic, and red oxide of lead, different red earths, madder, yellow ochre from Attica, Achaia, Lydia and Gaul; Scythian and Cyprian copper blue, Lapis Lazuli, cobalt, copper green, brown ochre, charcoal and Chinese black. For colors that are not suited to fresco painting, but require a chalk ground, and can be used also in encaustic, Pliny enumerates purple, indigo, cæruleum (Egyptian blue?) white clay earth from Melos, arsenic yellow, and appianum (a mixture of blue and vegetable yellow). We will here close.

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Gallo-Roman Tombs.—In working a gravel pit near Minversheim, Lower Alsace, four tombs were discovered, containing glass urns filled with ashes and calcined human bones. Three of the urns were enclosed in receptacles of Vosges freestone, rudely wrought. The clay and sand in the neighborhood were completely blackened and mixed with coal and potsherds to the depth of about a metre. This indicates the presence of a furnace designed for the burning of the bodies or the purification of the soil before burial or for other funeral rites. Three of the urns contained bones of adults. The fourth, which was of much smaller dimensions and adorned with lobe-shaped ornaments, enclosed the bones of a child. Besides the glass urns there were also found pitchers and vases of common pottery, a small amphora, a plate of sigillate clay, a Roman coin, tiles of different forms, as well as numerous fragments of pottery. The custom of burning the bodies is older than that of burial in stone sarcophagi. It ceased about the middle of the second century.—*Bulletin de la Société Industrielle*, November–December, 1884.

Plan for Lighting Paris.—M. Sébillot devised a plan in 1881 for a tower 300 metres in height in the Gardens of the Tuileries with a lighting apparatus of 2,000,000 carcels and a reflector with a double parabolic curve. In conjunction with M. Bourdet, he has given further study to the subject in connection with the successful applications of electric lighting in New York, Denver and elsewhere, and he thinks it would be possible to provide a single electric light, which would enable all the citizens of Paris to read ordinary print. He estimates the total gas light which is now employed for public lighting in Paris at 77,000 carcels, while his luminous focus would furnish, at much less cost, 2,000,000 carcels. He suggests the possibility of utilizing the water power of the dams around Paris.—*Électricien*, February 28, 1885.

# On the NEW SYSTEM of TELEGRAPHY to and from MOVING TRAINS, by the use of ELECTRIC INDUCTION.

By P. H. Van der Weyde, M. D.,
President of the New York Electrical Society.

[*Read at the stated meeting of the* Franklin Institute, *May 20, 1885.*]

Wm. T. Tatham, President in the Chair.

The President introduced Dr. P. H. Van der Weyde, who spoke as follows:

Human progress is the direct result of the discoveries how to make useful applications of substances of no value to uncivilized peoples. Coal and petroleum were stored up for countless ages in the bowels of our earth, utterly useless to the former occupants of this Continent, until scarcely a century ago the value of coal begun to be appreciated, while that of petroleum dates not much further back than a single decade.

Science and industry abound with so many illustrations of the utilization of formerly useless or waste substances, that it is scarcely necessary to enumerate more of them, while there are also many instances where such a utilization has been applied to materials which were a nuisance, not only to such a degree that ingenuity had been applied to determine the best way to dispose of them or to destroy them in the most economical manner.

It is self-evident that if it is meritorious to discover a useful application for useless materials, it is much more meritorious to discover a useful application for a substance which was not only useless but injurious—a downright nuisance.

These considerations do not only apply to material substances, but also to immaterial things, such as the mysterious agency, Electricity, of which that peculiar action, which we call induction, causes a variety of phenomena in the wires by which currents are transmitted, and which may also be called a nuisance, disturbing, as it does, the operation of telephones to such an extent that scores of suggestions have been patented, intended to destroy this nuisance, which, if now serious, while wires are suspended in the air, far

apart, will be much more so when these wires are laid close together, united in one or more cables and buried in a trench underground.

The credit of having made a useful application of this disturbing element and nuisance in telegraph wires belongs to Mr. Phelps, who recently conceived the happy idea to establish a communication of signals between a moving railway car and the stations along the railroad, by means of the mutual inductive influence of a conducting wire laid between the tracks and a similar wire suspended from a car, and parallel to the track wire, acting upon one another at a distance of several inches, which may be increased to several feet if so desired. The operation being solely based upon inductive action, requires, therefore, no contact whatsoever. Any method of contact between a moving train and the road over which it moves is necessarily very variable and uncertain, and this fact has been the cause of the failure of all former attempts to accomplish the telegraphic connection between railway stations and moving trains.

Before proceeding to explain the details of this new system of telegraphy, it may be well to give an explanation of the principle of induction, which I find is little understood, and often misunderstood. To my great surprise I have found this to be the case, even among men supposed to be competent electricians, some of whom I have heard maintain that induction was nothing but leakage of a current, which could be prevented by more perfect insulation than thus far has been applied. Now this is a grievous error; that what we call induction is no such thing as a loss of current, but a peculiar effect of the variations in a current upon neighboring conductors, which effects have been studied by Arago, Ampère, Faraday, Henry, and others. The results of these investigations have led to the knowledge of the laws, which govern this peculiar action. They are as follows:

(1.) Every electric current passing through a conducting wire, which we will call the primary wire, possesses the power to cause other electric currents to be generated or induced in neighboring wires, placed parallel or nearly parallel to the primary wire. These neighboring wires we call secondary wires, and the currents generated in them, secondary or induced currents.

(2.) Those secondary, or induced currents are not developed as long as the primary current generated by a galvanic battery,

dynamo, or any other source whatsoever, is steady; that is, invariable, or without fluctuation or interruption. Under these circumstances, a wire conducting a current exerts no more influence upon neighboring conductors than if there were no current at all in the primary wire.

(3.) As soon, however, as any change in the primary current takes place, currents are developed in neighboring wires, which are found to flow in the direction of the primary current at every break or decrease of the latter, and to flow in the opposite direction of that of the primary at every make or increase of the latter.

(4.) The strength and character of these induced currents depend upon several factors. 1. The electro-motive force of the primary current as measured in volts. 2. The quantity as measured in ampères.

Before proceeding further, it may be well to add here a few words in explanation of these terms, for the benefit of those present who are not familiar with what, at the present day, is known about electrical matters. While it is sure that electricity is not a fluid flowing through metallic wires, like water through pipes, it behaves in many respects, in a similar manner. Water drawn from pipes may flow in greater or smaller quantity, or it may escape under greater or less pressure, or head—two very different conditions. It is the same with electricity, which may flow through a wire in greater or smaller quantity, depending upon the size of the plates in the generating battery, or the thickness of the wires of the dynamo. The current may also flow with greater or smaller electro-motive force, which depends upon the number of battery cells connected, or the length of the wires of the dynamo. This explains to you what is meant when, in stating the qualities of a dynamo, the two terms ampères and volts are used. The first refers to the quantity of electricity produced, the second to the intensity, pressure or head under which it escapes. I ought to add here that in order to make a current dangerous, there must be enough of each. A current of great intensity, like that of a small friction machine, may have electro-motive force enough to jump over a space of one or more inches, and give a shock to the body, still it may be harmless if its quantity is so insufficient that it can hardly be measured; while on the other hand, the current of a very large voltaic cell may be powerful enough to burn up a piece of iron

wire, but will also be harmless, because it has not enough intensity to be able to pass through the human body. It is only when currents combine both conditions that they become dangerous, as is the case with large arc-light dynamos and with lightning.

The third factor upon which the strength of an induced current depends is the manner of fluctuation and interruption of the primary current, which may be more or less gradual or sudden, and causes the induced currents to display accordingly more or less electro-motive force, and less or more quantity.

The fourth factor is the mutual inclination under which the wires are placed, whether they are more or less perfectly parallel, while the amount of induction produced is proportional to the cosine of the angle which the wires make together. This cosine is at its maximum when the angle is zero, which is the case when the parallelism is perfect, and it is zero when at right angles, in which case there is no induction. This, by the way, has given rise to several patented devices, such as solenoid cables, interlaced conductors, etc., in all of which the inventors attempted to overcome inductive disturbances by crossing the conducting wires as much as possible at right angles. It is, however, evident *à priori*, and confirmed by experience, that such devices are not better than the straight, double metallic conductors as used by Morse with his first telegraph from Washington to Baltimore, before it was known that the earth could be used for the return currents, while the greater length of wire required increases unnecessarily the resistance, and reduces the distance accordingly, which would otherwise be reached by a given battery.

A fifth factor which influences the strength of inductive influence received by a secondary wire, is the distance under which it is placed from the primary wire; when close to it, the influence is at its maximum, while it decreases with the increase of distance, and this in the inverse ratio of the distance.

A sixth factor is the material which separates the wires; when this is a non-conductor, it is of comparatively little influence, except that the very best non-conductors interfere the least when inductive action is desired to be transmitted.

The seventh factor is the presence of other conducting *media* in the neighborhood. This is a very important matter, even when these *media* are not between the wires, but only within the sphere

of the inductive influence of the primary current. In this case, its inductive capacity may be so much spent or wasted by the induction of currents in these neighboring conducting *media*, that little inductive action is left for the secondary wire, in which we may wish to develop induced currents. This is the principle upon which many devices are based, serving to regulate the strength of induced currents, with which, however, we have no time to occupy ourselves at present.

I will now call your attention to the practical illustrations of the principal laws of induction which I have summarized. In order to make the motion of the galvanometer, by which the existence of currents is detected, visible to the whole audience, the little instrument is placed in the magic lantern which stands here among you, and the magnified image is projected on the screen behind the platform. You see that the galvanometer is connected with a flat coil of copper wire, which is laid on a glass plate resting on an insulating support at a distance above the table, and has no other connections whatsoever. On the table, under the support, rests another similar coil, connected with a galvanic battery by the intervention of a telegraph key. When I now depress the key, and thus close the current, you will see a movement of the galvanometer needle, but, as it returns at once to its original position, it shows that the current lasts only an instant, notwithstanding I keep the circuit closed, and thus make the battery current continuous. At the instant, however, that I lift my finger from the key, and thus break the current, you see the needle move again, but in the opposite direction, as before, proving that the secondary or induced current runs now in the opposite direction from the current developed at the instant of closing the primary circuit. This proves that the secondary currents are only developed by the making and breaking of the primaries, and, in fact, also by any fluctuations in their strength, as before mentioned.

As there is no conductive connection whatsoever between the battery and the galvanometer, to which I wish to draw again your special attention, it is evident that the latter instrument is acted upon by some other force than the direct battery current, namely, its inductive influence, which cannot be prevented by any intervening insulating material, but only modified and weakened by other

conducting bodies, placed within the sphere of the inductive influence. This latter fact, by the way, is the basis upon which the induction balance is based, by which the presence and positions of hidden metallic bodies may be detected, and which occasionally has been applied in surgical investigations.

The telephone being a more delicate apparatus than the galvanometer, we can by its means detect much weaker currents; in fact, such as are developed when we place the coils at several feet distance. I will now illustrate this by attaching, in place of the galvanometer, a telephone to the coil, and any one who wishes to listen can now become satisfied that inductive influence will act, not only at the distance of several inches but of several feet. I lift secondary coil several feet from the table on which the primary coil rests; in fact, I can lay the latter on the floor under the table, and still you will hear the click of the telegraph key in the telephone, showing how the ordinary Morse signals can be transmitted at a distance through the air, without any direct metallic connection.

This now is the basis upon which Phelps' telegraph system for moving trains is operated. The details of which will, by the kind coöperation of some of the officers of the Franklin Institute, be projected before you upon the screen.

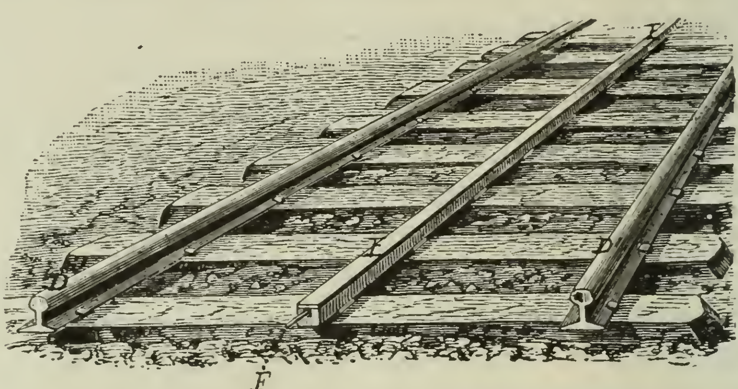


FIG. 1.

*Fig. 1.* represents a part of the road; between the rails is seen the wooden protection containing the main line, which is an insulated conducting wire, of which the two ends are connected at both stations, each of these containing a signaling and receiving apparatus, battery and ground connection.

*Fig. 2* represents a car, in one end of which, in a corner, is a closet containing also a signaling and receiving instrument, separ-

ately represented in *Fig. 3.* Inside the closet is the battery used for signaling from the train, and a single cell connected with a polarized relay, by which messages are received, and which is

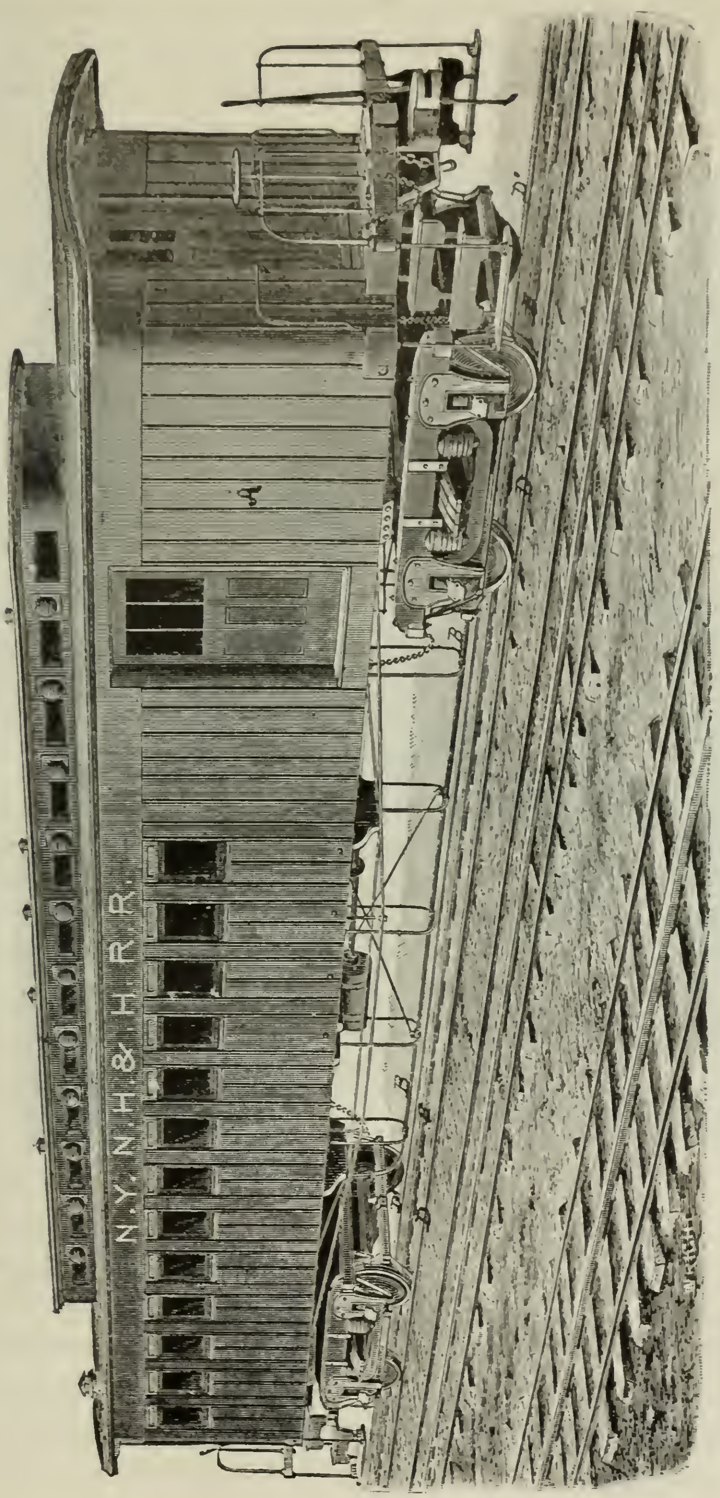


FIG. 2.

placed under a glass shade on the top of the closet, as seen in *Fig. 3*, and of which *Fig. 4* shows the details.

Under the middle of the car, *Fig. 2* is suspended an endless cable, properly protected against injury, and reaching to within eight or ten inches above the insulated conductor or main line between the rails, *Fig. 1*. This cable consists of one continuous

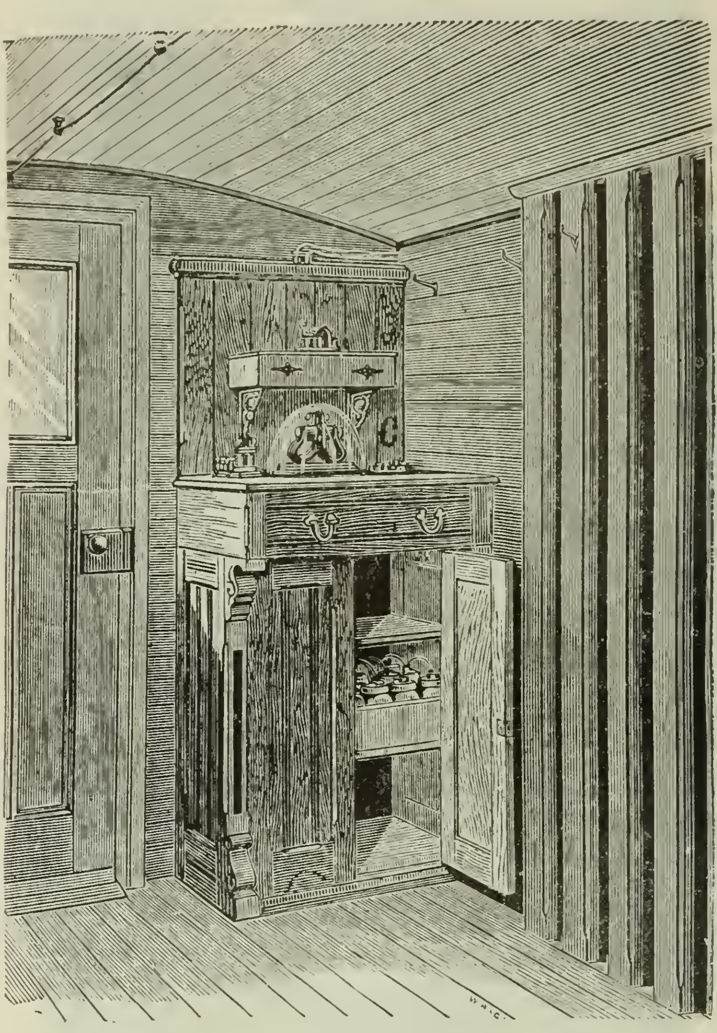

FIG. 3.

insulated wire, wound up like a coil, of some forty feet in diameter, of which one-half is under the car, and the other half near the top of the same, so that in the portion under the car the currents must all run in the same direction. In place of neutralizing one another by the contrary directions, therefore, the effect of induction is multiplied, the return half being as far as practicable away from the half under the car.

It is clear that if now a current is sent through the main line, *Fig. 1*, it must exert an inductive influence upon each and every wire in that portion of the cable nearest to it: that is, the portions suspended under the car, and the effect will be strengthened, in fact, to such a degree that when the two ends of the continuous wire constituting the endless cable are connected with the polarized relay, its tongue will be thrown from the right to the left, and *vice versa*, every time the current sent from either station through the main line is closed or interrupted, or what is more effective, every time the current is inverted. This polarized relay closes and opens the circuit of a single cell of the local battery, placed in the closet

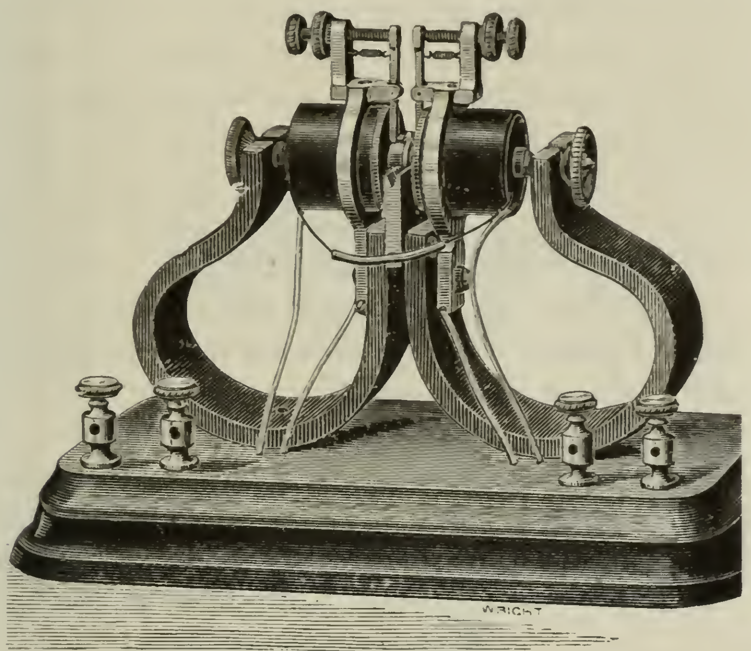

FIG. 4.

(*Fig. 3*), which cell works a sounder; or, what experience has proved to be more audible above the noise of a railway train, it is made to work an automatic contact-breaking buzzer, in which the dots and dashes of the Morse alphabet are given with more distinctness than is the case with the Morse sounder.

In order to signal from the moving train, a battery of four to six cells is used, of which the current is sent through the windings of the endless cable, the two ends of which windings are then connected with battery and key, or better, a reversing key. The battery current in the cable, multiplied by its windings, will now evolve induced currents in that portion of the main line under the

car, and this with sufficient energy to be made perceptible at the stations, in the same way that the currents evolved in the cable are received in the car, namely, with a polarized relay, local battery and sounder of any kind.

I have before mentioned the great sensitiveness of the telephone for weak currents, and its use has been found very advantageous, enabling the operator to receive signals even when the train runs on the track adjoining the one provided with the main line. In this case, the induction acts over a distance of eleven or twelve feet.

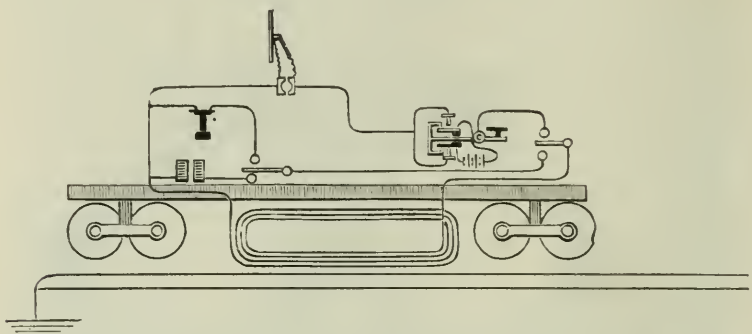

FIG. 5.

Our next projection (*Fig. 5*) gives, perhaps, a clearer idea of the operation. At the left side, is the receiving telephone and switches, at the right side, the battery and transmitting instru-

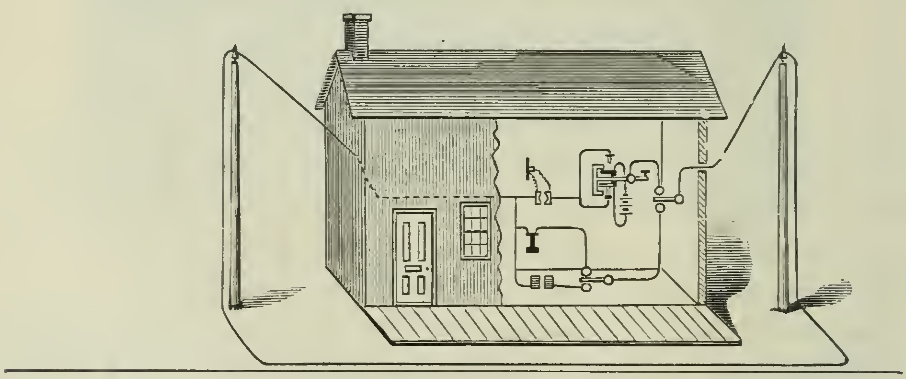

FIG 6.

ment; while here (*Fig. 6*), we have the interior of a station containing the same details, and receiving the signals by the action of

the main line upon a wire placed parallel to the same, and acted upon by induction after the same principle that the cars receive the messages.

I wish to call especial attention to the fact that the figures represented on the screen are no fancy sketches, but correct representations of the experimental car which is running daily from Harlem Bridge to New Rochelle, N. Y., and is attached to a local train between those two places.

The ELECTRICAL SOCIETY in New York was invited to visit an exhibit of this invention. Among the members were several practical telegraphers, who could not imagine the possibility of conveying intelligence through the air at a distance of one or more feet without any metallic connection. They said it is the old story: in order to start a stock company, it is only necessary to advertise something startling, in the Keely motor style, and make ignorant people believe in it. But I was satisfied that it could be done, because I had studied induction for many years, and I wanted to convert others. We had a meeting of the Society on board the car. They came in great numbers. The car was full. I wrote a despatch, and in order to convince unbelievers I wrote a copy of it, sealed it up and gave it to one of the members to put in his pocket. I sent a man along the track to catch the despatch some distance above the station. I was at the side door of the car when we passed the place, and saw the man pick up my despatch and go back to the station. As soon as he could have entered there the telegraph commenced to work on board the train, and in two or three minutes the operator handed me a despatch identical to the one I had sent. This was a satisfactory test, and did away with all possibility of any idea of collusion.

I made another experiment. While returning, I sent a message from the car to the next station, and the moment we arrived a messenger was on the platform and handed me a despatch which was identical with what I had sent. So, practically, there was no doubt about it. Any one who has studied induction can be satisfied with the possibility of the operation.

It is evident that in this way an always ready communication is established between any two stations, and the trains in the section between them, so that a train, no matter if in motion or at rest, can receive a signal sent from either station, and inversely can signal to

them. Of this I saw an illustration last week, when the brake connection gave out, it was at once telegraphed to the next station, and when arriving there a few men were already waiting on the platform with a new connection, and put it on without delaying the train. It is also found very useful to regulate with great despatch the movements of the hands employed, who, often, are suddenly needed at a particular place, even in the regular business, especially in regard to freight.

But the all-surpassing advantages of this system is that every station master knows always where the trains are in the section or sections under his control, and can stop or start them at any time, while the train conductor can at once report any accident to the stations, so that there is no doubt that several deplorable collisions and loss of life, still fresh in our memories, would have been prevented if this system had been invented and introduced some years ago.

The expense is comparatively a trifle, amounting to not more than the laying of a single insulated wire, properly protected, along the track; while the apparatus will cost scarcely $100 for both car and station. The wire costs only about double that of ordinary telegraph wire on poles above ground.

DISCUSSION.

THE SECRETARY.—" Mr. President, I think it is best to defer further practical illustrations till the close of the meeting, when the members can listen at the telephone, hear the signals, etc."

THE PRESIDENT.—" Any question on this interesting subject ?"

THE SECRETARY.—" Mr. President, it seems to me, unless I very much over-estimate the value of this invention, if it is practically operative, as Dr. Van der Weyde has given us to understand—and I have not the least doubt that it is, from the accounts I have read of it, and his lucid explanations—it seems to me that it opens an entirely new field in the application of electricity to railways, and that it is an invention of the highest importance. As all present are aware, the railway companies of this and other countries have expended large sums of money in the establishment of very expensive plans for signaling, *despatching trains*, etc., for the purpose of effecting safety. It must occur to any mechanical mind that a practical system whereby telegraphic or telephonic despatches may be received on a moving train, and sent from a moving train, must

be infinitely more safe than the most perfect automatic signaling system that could be devised. From this point of view, I am satisfied that the Phelps system, if not itself a solution of the problem, is a great step towards it, and certainly a very important invention."

A Member.—"I notice in his drawing that it appeared at the station as though a secondary wire were connected with the key. I would ask if it is the primary wire connected with the battery at the station, or is it a secondary wire similar to the one on the train?"

Dr. Van der Weyde.—"At the end stations no secondary wires are used. They switch the battery off and switch on the telephone. *Fig. 6* represents a way-station, not connected with the main line, but receiving the signals from the main line, by induction through a secondary wire, laid along the track, on the same principle that the cars receive the signals."

[After answering a few more questions, a further opportunity was given to many of the audience to hear the signals in a number of telephones, connected with the secondary wire, placed from the primary at distances varying from six inches to six feet, where they were still audible, even when several persons placed themselves between the primary and secondary coils. This was similar to an experience of last winter, when snow and slush, entirely covering the main line between the track, did not in the least interfere with the transmission of the signals.]

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Delta Metal.—More than twenty years ago, Aich and Baron Rosthorn obtained good results by introducing a little iron into alloys of copper and zinc. A London coppersmith, who made such alloys, informed Alexander Dick, of Düsseldorf, that he sometimes obtained an excellent metal, but that the results were so irregular, that he was obliged to give up its use. M. Dick studied the causes of the irregularity and found that they could be mostly overcome by dissolving iron to saturation in melted zinc and adding the alloy, with or without additional zinc, to melted copper. A small proportion of phosphorus prevented injurious oxidation during the process. An extensive and complete series of experiments led to the discovery of a number of definite and valuable products, each of which has special useful properties, all being included under the common name of delta metal, *delta* being the Greek name of the initial letter of the inventor's surname.—*Société des Ingénieurs Civ.*, October, 1884.

# A LECTURE ON "MATTER," INCLUDING "RADIANT MATTER."

BY ALEXANDER E. OUTERBRIDGE, JR.

[*Delivered at the International Electrical Exhibition of the* FRANKLIN INSTITUTE, *October 9, 1884.*]

The Chairman of the Committee on Exhibitions introduced the lecturer, stating that, by request of the Committee, Mr. Outerbridge would repeat an address, which he delivered before the INSTITUTE in 1881, adding thereto the results of some of the more recent investigations on the nature of matter. The lecturer, after a few introductory words, spoke as follows:

The ideas which have prevailed in the past, in regard to the nature of the ultimate particles of matter out of which worlds are formed, reveal the speculative tendency, as well as the intellectual status, of the human mind in different epochs of the history of civilization. The present era might very well be designated as an interrogatory age, for is there not an evident tendency to question Nature eagerly, to accept nothing on the evidence of tradition, and but little comparatively on the basis of pure hypothesis?

Plausible explanations of various phenomena have so often been accepted with confidence, only to be overthrown by others equally unstable, that the mind has become, as it were, suspicious, and demands the most rigid physical tests to corroborate new theories. The experimental feature of scientific study has thus been stimulated until it has attained an importance and perfection never before approached, and this cause largely contributes to popularize even the most abstruse subjects of inquiry. It is one of the little pathways through the intricate mazes of Nature's mysterious realms that we propose to explore together this evening.

The question, "*What is matter?*" is one that has exercised the intellects of the profoundest thinkers in all ages, and it is, apparently, as far from being definitely answered in this nineteenth century as in the classic days of the Greek philosophers. It would seem, indeed, that the modern views of matter, based upon strictly scientific data and mathematical reasoning, approach in some respects quite closely to those propounded by the Attic

philosophers, which were evolved purely from the inner consciousness of these poetic sages and must be regarded rather as expressions of sentiment than as deductions from observed facts. The poetical fancies of Lucretius, which have been preserved to us in his great work, "*De Rerum Natura*," through a lapse of 2,000 years, may be read with renewed interest in the light of modern scientific thought.

The delicacy of the apparatus devised by modern physicists, and the refinement of experimental research rendered possible thereby, are among the greatest marvels of this wonderful age. The physicist is pushing his researches into paths which but a few years ago were thought to be forever hidden somewhere in the vast realm of the "unknowable," and the boundary line between so-called physical and metaphysical science is continually narrowing; the philosopher has advanced, step by step, until he seems almost to have grasped the ultimate particles which constitute the physical basis of the universe, and to have revealed to mortal eyes particles of matter which are too minute even for the mind's eye to conceive.

Our ideas of size and weight are purely relative, and that which appears a small or light object from one point of view, may become large and heavy by a different comparison. To most of us, perhaps, a "grain weight" suggests a little thing; we know that the apothecary and a few other exact dealers split up the grain into halves, quarters, tenths, and perhaps even hundredths, but we are apt to regard such discriminations as bordering on the fanciful; yet, strange to say, there seems to be a sort of vanishing point in our minds, beyond which, if an object is small enough to pass, it becomes larger and more important in our estimation by reason of our astonishment at its minuteness. The most ordinary microscopical specimen is an illustration of this, but when we realize that the ability of the spectroscope to reveal small particles of matter begins where the finest microscope searches with its highest power in vain, that the grain of matter may be divided, not merely into hundredths, or thousandths, or tens of thousandths, but into millionths and tens of millionths, and that a single one of these particles may be readily detected by this little searcher and held up for our inspection, our wonder and amazement enhance our respect for its occult powers.

The astronomer tells us that a comet often throws out a tail longer than the distance between the earth and the sun, and broad

in proportion; yet the matter forming this tail is so attenuated that, if it could all be gathered up and properly compressed, it might be carted away in a wheelbarrow, yet we have merely to point this little tell-tale at the comet and instantly we perceive what the matter is! Think of it! Not merely may we grasp infinitesimal particles at our hand, but we may sweep the firmament, "gather up the star dust" and tell its composition. But we have not yet reached the end of our scientific excursion; indeed, we have only entered the threshold of the scientist's sanctum, and the wonders of the arcanum eclipse those of the portico.

That mysterious agency, or force, called electricity, has been utilized not only for hundreds of practical purposes, so fully illustrated in this grand exhibition, but it has been employed by the physicist as a sort of fairy finger to probe Nature's inmost structure, and it has enabled him not only, as it were, to see her mind but, in some sense, to feel her pulse.

Professor Crookes, in his beautiful investigations on "radiant matter," has availed himself of this index, with the most surprising results. Here are a number of his tubes and bulbs, from which he has exhausted the air until only about $\frac{1}{1,000,000}$th part of the original quantity remains. We may regard this residual matter as consisting of many millions of individual molecules, and we can capture these minute particles and compel them to do tangible work. This tube, for example, contains a sort of miniature railway, which is to be operated by projecting these particles with great force against the driving wheel of the engine. Here is a little wind-mill which is to be similarly driven. Here is a tube containing a piece of refractory metal, platinum, which is to be so terribly battered by hitting it with a rapid succession of charges of these molecular bullets, that it is made to glow with a bright light, and if the bombardment should be continued to melt before it like wax. Here is a tube containing a common piece of chalk which may be made to shine with a luminosity rivalling the famous "Koh-i-noor." Even little pieces of glass may outshine the finest emeralds, rubies, and sapphires, when under the marvellous influence of this philosopher's wand.

You must not imagine that these little tubes are merely scientific toys, they are designed to illustrate new properties of matter; but before exhibiting their beautiful effects, I wish to familiarize you

with some of the modern ideas in regard to the nature of the ultimate particles of matter. I am sensible of the difficulty of attempting to elucidate to a general audience, in a brief period of time, a subject so abstruse in character, so bound up in mathematical deductions and dealing with such minute figures as this. I shall try, therefore, to lead you by gradual and easy steps up to that point of observation from which the philosopher reviews, by the aid of his acute mental vision, the transcendent processes eternally operating in Nature's workshop, whereby the most complex structures are evolved from simple elements.

The idea that motion is intimately associated with all matter in some way is not a modern notion, and it was regarded by Faraday's far-reaching mind as a sort of necessary concomitant of familiar matter, though the time was not yet ripe for its full development as a scientific theory. The great forces, light, heat and electricity, were formerly thought to be ponderable substances, which might be squeezed out of a body like water from a sponge; now they have all been resolved into mere "modes of motion," and it is not illogical to infer, from the general drift of modern scientific speculation, that the now seemingly complex laws of Nature's operations may all come, eventually, to be included in the study of the laws of motion.

Sir William Thomson said, in his address at the meeting of the British Association in Montreal: "It is scarcely possible to help anticipating, in idea, the arrival at *a complete theory of matter in which all its properties will be seen to be merely attributes of motion.*"

Before endeavoring to explain such a strange proposition (for it must, no doubt, at first, impress an intellectual person who is not familiar with the course of reasoning upon which it is predicated, as incomprehensible), it will be well to consider briefly some of the properties of matter with which we are more familiar, such as its wonderful divisibility, its universal porosity, and its universal transparency. The metal gold, for example, is susceptible of visible dissection to a remarkable degree. The gold beater, as you doubtless know, will hammer out the metal into leaves so thin that more than 4,000 are required to make a pile one millimetre in thickness. But vastly thinner gold leaves may be obtained in another way. By electro-plating a known weight of

gold upon one side of a sheet of copper foil of given dimensions, a coating of gold may be obtained upon the copper whose thickness is readily ascertainable by a simple calculation; then, by using a suitable solvent, the copper may be removed, when the leaf of gold will remain intact.

After a series of careful experiments, I have obtained, in this way, sheets of gold, mounted on glass plates, which are not more than $\frac{1}{40,000}$th of a millimetre thick; and I have some specimens to show you which I have good reason to believe are not more than $\frac{1}{400,000}$th of a millimetre. To give you an idea of this thickness, or, rather, thinness, I may say that it is about $\frac{1}{200}$th part of a single wave-length of light. Such figures are not hap-hazard guesses, but are based upon reliable and understandable data, and are easily susceptible of verification.

We cannot claim for the thinnest of these films that they represent a single layer of molecules. Taking Sir William Thomson's estimate of the size of the final molecules, and considering that each layer corresponds to one page of a book, our thinnest film would then make a pamphlet having more than a hundred pages. It is found that when such a film is interposed between the eye and any object, it is as transparent as a piece of glass. This may be readily proved by projecting a picture on the screen and interposing the leaf of gold in the path of the light and you see that the only apparent effect is to tinge the light a pale greenish color, none of the detail of the picture is lost, though all the light is coming through a piece of gold as absolutely continuous in its structure, when examined under a microscope, as though it were an inch thick. By placing in the lantern a piece of ordinary gold leaf, having a thickness of about $\frac{1}{200,000}$th of an inch, and a piece of electro-plated gold leaf about $\frac{1}{3,000,000}$th of an inch thick, mounted side by side on a glass slide and focusing their images on the screen, you will see a very great difference in the amount of light transmitted by the two, owing to the difference of thickness. Plates of platinum and other metals similarly prepared are equally transparent; indeed, all metals, and probably all substances are transparent when reduced to sufficiently thin plates.

Faraday made some most interesting investigations on the size of finely-divided particles of gold diffused through various liquids and he obtained gold films by reducing gold from solution by phosphorus

which he thought were not over $\frac{1}{100}$th part of a single wave length of light, but he had no means of determining their thickness accurately as we have in the case of these electro-gold films, where, knowing the weight of gold deposited and the surface covered, the exact thickness may be directly calculated. By treating these thin films after they are attached to the glass plate with a weak solution of potassium cyanide they may be still further reduced in thickness until the film becomes so transparent as to be incapable of reflecting the usual gold color.

Tyndall tells us that the blue color of the sky is due to reflection of light from innumerable particles or spherules of floating matter. He has reproduced the sky phenomena by artificial means, and he tells us that the matter forming the real sky is so attenuated that if it could be properly gathered up and compressed, a gentleman's portmanteau would probably hold it all; and he says, further, "Whether the actual sky be capable of this amount of condensation or not, I entertain no doubt that a sky quite as vast as ours, and as good in appearance, can be formed from a quantity of matter which might be held in the hollow of the hand."

We might naturally suppose from these considerations that no absolute knowledge could ever be obtained regarding the nature of the infinitesimal particles out of which worlds are formed. It was thought in former days that the human mind could never hope to take cognizance of such minute portions of matter as constitute the ultimate molecule. One very eminent scientist said, "Data cannot be furnished by observation or experiment on which to found an investigation of it." Yet so great has been the progress of thought in recent years, aided by the wonderfully delicate means of research at command of the modern physicist, that Sir Wm. Thomson now claims that the ultimate molecules are "pieces of matter measurable dimensions, with shape, motion, and laws of action: of intelligible subjects of scientific investigation." The same eminent author has deduced, by four different and equally profound methods of calculation, the probable size of these molecules, and in order to make his dimensions intelligible to ordinary people, he asks us to imagine a single drop of water magnified to the size of the earth, the molecules of which it is composed being increased in the same proportion, "the structure of the mass would then be coarser than that of a heap of fine shot, but not so coarse as that of a heap

of cricket balls." You know that the gases oxygen and hydrogen when united to form water are greatly compressed, yet the atoms are far from being in actual contact; the estimate has been made that the particles composing a drop of water are not nearer together when compared with the spaces between them, "than 150 men would be if scattered over the whole of England, or one man to 400 square miles." To the ordinary mind this seems incredible.

In order to comprehend the modern idea of the nature of matter, you should try to realize that the molecules composing even the most dense solid substances with which we are familiar (such as gold, platinum, etc.,) are not in contact, and are free to move within certain well-defined limits. In the fluid condition of matter, these particles have a wider range of motion; while in the gaseous state, the excursions of the molecules are limited only by the size of the containing vessel.

All the phenomena of gases are now explained upon the assumption that the molecules are constantly flying about and hitting against each other, and the characteristic properties of gases are directly traced to this state of constant collision among the molecules; in scientific phraseology, this dictum is called "the kinetic theory of gases."

Professor Crookes has gone still farther upon this road; by exhausting the air from his tubes to a very high degree of rarefaction, he has so greatly decreased the number of molecules and correspondingly increased their house room, that collisions occur among them as they fly about with far less frequency than before, hence the ordinary characteristics of gases disappear, while a whole new series of phenomena are developed. It is upon the visible evidence afforded by the peculiar behavior of the so-called "radiant matter" in these tubes, when under electrical excitation, that Professor Crookes rests his claim to have revealed matter in a state "as far removed from gas as gas is from liquid, or liquid from solid," and he calls this new condition the "fourth state of matter." Whether this claim rests upon a sure foundation and is destined to be recognized as true, I do not venture to form a decided opinion, but that he has revealed new phenomena of a surprising and beautiful nature, we have incontestable evidence before us in these remarkable radiant matter tubes.

Now, let us try to approach a little nearer to an understanding of the idea recently elaborated by Sir Wm. Thomson, in his Mon-

treal address (entitled, "Steps toward a Kinetic Theory of Matter,") that all the properties of matter with which we are familiar are merely attributes of motion. Those of you who heard his lecture in this city, on the "Wave Theory of Light," will remember that he said that the luminiferous ether is no longer to be regarded as hypothetical, but that it is one thing which we are sure of; furthermore, that it may be regarded as a substance having great rigidity, and therefore capable of acquiring motion at the rate of millions and millions of vibrations per second—in the case of visible light waves giving from 400,000,000,000,000 to 800,000,000,000,000 per second.

Now with regard to the character of the atom. Suppose that a particle of this all-pervading, highly-attenuated, rigid yet elastic substance, which, for want of a more appropriate name, is called "the luminiferous ether," be endowed, by a creative act, with rotary motion; it is evident, to a thinking mind, that new properties would be imparted to the particle by virtue of this motion, just as new powers are imparted to grains of sand when caught up and carried along in a whirlwind, or to particles of water forming a water-spout. Suppose that no opposing forces, like gravitation, tend to annul this motion, then the particle will remain forever differentiated from the great mass of ether in which it has its being. This is the simplest explanation, as I understand it, of Sir Wm. Thomson's "vortex-atom," he believes that "what we call matter," may be only the rotating portions of something which fills the whole of space.

Helmholtz's investigations on the nature of rotary motion, in a theoretically perfect fluid, prepared the way for the vortex-atom, and the now well developed "kinetic theory of gases" is the natural precursor of the "kinetic theory of matter," which, although still in the embryonic stage, gives promise of developing into more than a mere scientific speculation, and of emerging into an accepted theorem. The creation of a new theory is generally, and very properly, a slow process; for when once established it clings tenaciously to the mind, and if fallacious, it sometimes fetters the progress of human thought for many generations.

Following in this mental path, Professor P. G. Tait says: "This property of rotation may be the basis of all that appeals to our senses as matter." Professor Crookes likewise says: "The space

covered by the motion of molecules has no more right to be called matter than the air, traversed by a rifle bullet, to be called lead." Again he says: "From this point of view then matter is but a mode of motion."

In order to render the distinctive characteristics of Professor Crookes' radiant matter phenomena apparent to those not already familiar with the subject, we will first exhibit a number of very beautiful Geissler tubes, *i. e.*, tubes from which the air has been only partially removed. These tubes are of great size, and are marvels of the glass-blower's art. You will observe that the tubes are of various and complicated form, and contain spirals, bulbs, and goblets of different kinds of glass. A platinum wire is hermetically sealed into each end of the tubes. Here is a large coil of wire, called an "induction coil," having a smaller central coil which you do not see. A galvanic battery on the stage supplies an electric current which passes through the centre coil; an automatic break piece makes and breaks connection rapidly between this coil and the battery; the terminal wires from the large exterior coil are connected with the platinum wires entering the Geissler tube; when the electric lights illuminating the room are extinguished and the battery is put in operation, a succession of induced electric pulsations of high tension will be sent from this exterior coil into the tube. Now, you see it filled with brilliant and beautiful light. Observe that the electric flashes seem to pervade the whole tube, and to follow all its intricate twists and turns. Here is another tube exhibiting the curious phenomenon of "stratification" in a remarkable way. Here is another, which is divided into separate compartments containing traces of different gases, and you see that the color of the light is different for each gas.

Passing on, now, to the Crookes tubes, we will show them in the order adopted by Professor Crookes, on the occasion of his original address before the British Association, projecting on the screen, at the same time, diagrams showing their mechanism, omitting some tubes which have become injured on the journey across the water, and including others of recent device.

The tube having a negative terminal in the centre and a positive one at each end, showing the "dark space" surrounding the negative pole and exhibiting "the mean free path" of the molecules, is most interesting.

Another tube with one negative and three positive terminals showing that radiant matter always travels in straight lines independently of the position of the positive pole, and still another showing that radiant matter will not turn a corner, prove conclusively that the phenomena differ widely from those exhibited in the Geissler tubes, where the electric current followed all the convolutions of the tube, entering at one terminal and emerging at the other.

[The tubes showing mechanical action were exhibited by projecting the images of the moving vanes, etc., upon a screen by means of a lantern.*]

The lecturer said, in conclusion: Although I am conscious of having imperfectly succeeded in my effort to elucidate so large a subject as the modern conception of the nature of matter, in the brief time allowed, I still venture to hope that this little glimpse I have given you into the minute world of molecules and atoms (which has been compared to the great world in which the stars revolve), may tempt you to explore more deeply the interesting paths of knowledge here indicated, which have been opened to view by toiling investigators who have taken the light of "pure science" for their guide and have done much to enlarge the horizon of our mental vision and to expand our intellectual capacities.

It is interesting to note how frequently it happens that original investigators, working from different standpoints and with dissimilar objects in view, will, independently of each other, accumulate a mass of observations all tending to elucidate some hitherto unexplained physical law, which only require to be collated in order to reveal their true significance.

Such an original investigator in Nature's domains may be compared to a pioneer who penetrates a primeval forest, hewing down, with his keen hatchet, first a narrow pathway through the wilderness which he explores, until he reaches a favorable camping ground; he then clears a space admitting sun-light and air and

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* A detailed description of Professor Crookes' "Radiant Matter" will be found in the JOURNAL OF THE FRANKLIN INSTITUTE, vol. cviii., No 5, p. 305, and a reprint of Professor Crookes' papers on the subject with illustrations, has been prepared by Messrs. J. W. Queen & Co., of this city, from whose exhibit the apparatus used in this lecture was obtained. For these reasons the details of these beautiful experiments are omitted in this report.

erects his habitation; meanwhile, perhaps, other adventurers approach through the forest from different directions; presently the clearings begin to encroach upon each other, cultivated fields appear, the rugged face of the landscape gradually changes, its every aspect becomes familiar, and its once strange and novel features cease to excite wonder or remark. This analogy is not a mere fancy, all the advances in scientific knowledge have been made in little detachments. Narrow lines of investigation have been projected and explored by patient toilers who dig out a few roots here and there, which are carefully garnered until their genus can be determined by further study. In this way separate facts are being constantly stored up, to be collated and classified at a proper time.

While we, matter-of-fact people, may not understand the motive that induces the original investigator to plod on in his narrow path, continually prying into some obscure corner of Nature's vast forest of mysteries, we can all appreciate and enjoy the beautiful results which modern science offers as rewards to her votaries, and we cannot too greatly venerate the genius of those who could conceive the possibility of such results and who possess the ability to produce them.

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CELLULAR STRUCTURE OF CAST STEEL.—MM. Osmond and Werth have been experimenting for several years in the laboratory at the workshops of Creusot upon the structure of melted steel. Preparing plates as thin as possible and fixing them to glass by the aid of Canada balsam, they were exposed to cold, weak nitric acid until the iron was dissolved, leaving a nitrate derivative of a hydrate of carbon, so as to reveal the distribution of the carbon in the steel. A microscopic examination shows that this distribution is by no means uniform and that melted steel is composed of small granulations of soft iron, which are generally separated from one another by cells of a carburet of iron. In other words, there is a kind of cellular tissue, the iron constituting the nucleus, and the carburet the walls of the cellules. These elementary or simple cellules are collected into compound cellules, which are separated by void lines. The lines form closed polygons, which are of large dimensions in the cast ingots, but which become smaller and smaller, broken and confused, in proportion as the metal is more perfectly worked. The contact faces of the compound cellules are composed of soft iron without the interposition of carburet. The compound cells may be readily identified with the grain of the steel and their faces are also regions of minimum cohesion.—*Comptes Rendus*, February 16, 1885.

# FRICTION OF LEATHER BELTS ON IRON PULLEYS.

By Silas W. Holman.

The present investigation (completed in 1882) was undertaken with a double object: First, to make a somewhat more detailed study of the variation of friction with changes of velocity of slip in a few substances, and to make a further study of the friction of belts of leather and other materials over the surfaces of pulleys. It was also desired to ascertain how far the necessary arrangements would be suitable for an instructive laboratory experiment for students; a problem which has since been brought to a very satisfactory solution by others in the Mechanical Engineering Laboratory of the Massachusetts Institute of Technology.

The laws of friction between rubbing metallic surfaces, both lubricated and without lubricant, are yet open to careful research. Although the conditions of this case are comparatively simple, they are yet somewhat difficult of exact reproduction. The presence of dirt or traces of any material, which may act as a lubricant, must produce serious errors in the result. The complete removal of oil, used in the preparation of the surfaces, has been found a matter of difficulty, and this shows that all such use of oil should be avoided. The measurements of Coulomb, Morin, and Jenkin go far to show that with speeds from 0·1 inch per minute up to perhaps 5,000 inches per minute, the coefficient of friction of motion (kinetic friction) of many unlubricated metallic surfaces undergoes but little change; also, that the coefficient of friction of repose (static friction) is nearly, if not quite, the same as of motion.

It is to be noted, however, that the magnitudes of the errors in the experiments of the first two observers are so great, that it is impossible to claim that there is no change whatever, even within much narrower limits. Jenkin's measurements extend only from velocities of 0·1 inch per minute to 8 inches per minute, about, and although quite delicate, cannot be regarded as sufficiently numerous or positive to be of conclusive weight. The experiments of Bochet, upon the friction of iron at higher speeds, from four to twenty-two metres per second = 10,000 inches to 50,000 inches per minute, were made upon the action of brakes upon rail-

way trains, and show a decided diminution in the coefficient as the speed increases.

These are all the published experiments upon this point, with which I have met, but I have not entered into a careful study of the literature of the subject. The case of friction of metals upon wood without lubricant has been studied by Coulomb, Morin, and Jenkin, with the same general result. Kimball has shown, however, a diminution in coefficient with increase of speed in this case also, but finds further that the coefficient of friction in general "at very low velocities (under a few inches a minute) is very small; it increases rapidly at first, then more gradually as the velocity increases, until at a certain rate, which depends upon the nature of the surfaces in contact and the intensity of the pressure, a maximum coefficient is reached. As the velocity continues to increase beyond this point, the ccefficient decreases. An increase in the intensity of the pressure changes the position of the maximum coefficient, and makes it correspond to a smaller velocity," etc.

When the experiments on lubricated surfaces of whatever description are considered, it will be seen that the discrepancies are far greater than with unlubricated. This is doubtless due chiefly to irregularity in the amount of the lubricant present, to a want of sufficient regard to the nature of the lubricant used, and to other similar experimental conditions. It seems unlikely that experiments upon plates sliding upon a horizontal plane with uniform motion, would give conditions of lubrication identical with similar plates moving with accelerated motion, with shafts revolving in journals, and with disks revolving one against the other.

Morin has found constant coefficients for lubricated metals, and Jenkin has arrived at sensibly the same result for very low velocities, with the exception of steel on steel with oil. For this he finds an increase of the coefficient as the speed increases. Kimball finds under conditions similar to those used by Jenkin, a similar rise in coefficient, attaining a maximum at a low speed (of about one inch per minute, or less in case cited) and then falling away towards a minimum of much smaller value (as low as one-third the maximum in one case) at high speed. The experiments of Jenkin and Kimball are on shafts upon their bearings.

In the case of metals upon wood with lubricant, the general result of Jenkin's experiments point to a rapid diminution of

coefficient as speed increases up to about eight inches per minute, and even higher. Observations of Morin give to these substances a static coefficient higher than the kinetic, and the remark made by Jenkin connecting these phenomena is a suggestive one.

The results of Coulomb, Rennie, Morin, Jenkin and Kimball are not, I think, to be regarded as contradictory. It must be considered that the measurements by Jenkin were at velocities in inches per minute from 0·1 to 8; by Kimball, from 0·007 to 3,000; by Morin, 70 to 9,000 (certainly not reliable below 70); by Bochet 10,000 to 50,000. Thus the experiments of Jenkin and Morin scarcely overlap, those of Morin and Bochet do perhaps slightly overlap, and those of Kimball cover a range corresponding to those of Jenkin and most of those of Morin, and extend considerably below those of the former. The results by Kimball and Jenkin are not contradictory and the data by Bochet seem to be a continuation of Kimball's results about such as might be anticipated. The field, as it is now opened, would seem, therefore, to invite a careful detailed study with the whole range of materials and velocities, under conditions of accuracy corresponding to the possibilities of modern mechanical construction, so that a *connected* series of reliable data should be reached.

Although my own work progressed but a little in the direction of the friction of solids, and none of the results are here given, I leave the above statement to present for comparison the results upon the friction of metals and those now to be described upon the friction of leather and iron.

Before I had become acquainted with the methods and results of Professor Kimball,* I had been led by some preliminary experiments both on the friction of blocks of wood upon inclined and upon horizontal planes, and on the friction of belts upon pulleys, to the conclusion that, at low speeds, the coefficient of friction did increase rapidly with the speed. Seeing the important bearing of this fact upon the question of the friction of belts upon pulleys, I have been led to an extension of these preliminary experiments to a more detailed study, in the hope of being able to demonstrate clearly for some special cases the law of the change of coefficient, and to thereby contribute somewhat to an interesting theoretical

*A. S. Kimball. *American Journal of Science*, cxiii. (1877).

question and to the data used in engineering practice in regard to belting

In the case of a belt sliding over the surface of a pulley, there appears to be no objection to the use of the general formula of Morin,* giving as the coefficient of sliding friction:

$$f = \frac{\log_{10} \frac{T}{t}}{0{\cdot}00758\, a}$$

where $T =$ tension in tight side of belt,

$t =$ tension in slack side of belt,

$a =$ arc of contact between belt and pulley.

When $a = 180°$, this becomes

$$f = \frac{\log_{10} \frac{T}{t}}{1{\cdot}364}.$$

This expression must not be applied to rapidly running pulleys without allowance for "centrifugal force" of the belt, but in the present study no such condition enters.

A complete description of the apparatus used in my experiments is unnecessary. In principle, it was as follows: A pulley was fixed upon a horizontal shaft, which could be kept in continuous and quite uniform rotation at any desired speed from zero to about thirty turns per minute. Over this pulley was hung the belt, whose coefficient of friction was to be measured, and to this was attached at one end (usually corresponding to the slack side of the belt) a spring balance reading up to 120 pounds, which was secured at its other end to a ring in the floor. Both ends of the belt were also provided with hooks, upon which weights could be hung.

To determine the rate of slip of the belt over the surface of the pulley, an electrical chronograph was improvised from a Morse sounder. By this were recorded seconds by means of a circuit closed by a seconds pendulum, and upon the same strip the times at which four electrical contacts were closed by a pointer attached to and revolving with the

* "Morin's Mechanics." "Rankine's App. Mechanics," p. 618.

shaft carrying the pulley. A careful measurement was made once for all of the distance through which the highest point on the crowned surface of the pulley moved, when the pointer passed from each of these contacts to the next. Thus by the chronographic record, the time during which the pulley surface turned through, a known distance under the belt was given, and from this the rate of slip was deduced by a direct proportion. All rates of slip were used from the highest attainable, which were far beyond the limits of practice, down to the lowest, which were not interfered with by the friction of repose. The tables show the rates used. Care was taken in all measurements of any series with any given belt, to use as far as possible always the same portion of the belt surface. With this precaution it was found that the arrangement was very sensitive, and would give very accordant results so long as the condition of the belt surface remained the same. The following tables give some of the results obtained.

FIRST SERIES.

Belt used, three inch, single, old, leather belt, moderately clean.

Pulley used, 13 inch x 4 inch iron pulley, with very smooth, polished face.

Tension $T$, on tight side of belt = 20·3 pounds.

| $t$ Pounds. | $f$ | *Slip.* in. per m. | $t$ Pounds. | $f$ | *Slip.* in per m. |
|---|---|---|---|---|---|
| 14·03 | 0·118 | 0·72 | 11·59 | 0·171 | 13·20 |
| 13·69 | ·125 | 0·83 | 9·56 | ·240 | 18·00 |
| 12·25 | ·160 | 3·00 | 9·56 | ·240 | 18·00 |
| 13·75 | ·123 | 1·15 | 13·34 | ·135 | 1·44 |
| 13·56 | ·128 | 1·15 | 13·38 | ·132 | 1·65 |
| 13·44 | ·132 | 1·32 | 14·47 | ·107 | 0·288 |
| 11·69 | ·175 | 5·76 | 14·50 | ·107 | 0·144 |
| 11·44 | ·184 | 6·60 | 14·56 | ·105 | 0·096 |
| 14·19 | ·114 | 0·48 | 5·44 | ·493 | 140· |
| 14·06 | ·116 | 0·48 | 4·19 | ·502 | 279· |
| 14·00 | ·118 | 0·55 | 3·31 | ·578 | 558· |
| 11·81 | ·173 | 11·52 | 3·19 | ·590 | 558· |
| 11·56 | ·141 | 13·20 | 6·31 | ·372 | 69·7 |
| 11·81 | ·137 | 11·52 | 8·06 | ·294 | 27·9 |

This series was made with a preliminary apparatus before the chronographic speed recorder was arranged. If the results be plotted with speeds as abscisses and values of the coefficient of friction $f$ as ordinates, it will be found that the results are quite

concordant, and that they show a great change in the coefficient with change of rate of slip. An inspection of the tables will show that with the slowest slip, 0·096 inches per minute, the smallest coefficient, 0·105, was obtained; with the most rapid slip used, 558 inches per minute, the largest coefficient, 0·590 (or mean 0·584) was found. The increase in coefficient is very rapid for slow rates of slip. The consideration of such a plot for the later series, as that just suggested, will contribute greatly to a clear conception of the results. In this series no friction of repose as distinguished from that of motion was observable. Prolonging the line obtained by the plot backward to a slip of zero gives the very low coefficient of friction $f = 0{\cdot}100$, a result which is discoverable, I think, solely because of the fact that my observations give results at such low rates of slip.

### SECOND SERIES.

Belt used same as in first series.

Pulley used same as in first series.

Tension $T$, on tight side of belt, 50·4 pounds.

| $t$ Pounds. | | *Slip.* in. per m. | $t$ Pounds. | $f$ | *Slip.* in. per m. |
|---|---|---|---|---|---|
| 34·0 | 0·125 | 0·720 | 25·6 | 0·216 | 13·20 |
| 36·2 | ·106 | 0·240 | 35·7 | ·110 | 0·288 |
| 34·4 | ·122 | 0·825 | 36·1 | ·106 | 0·170 |
| 33·0 | ·135 | 1·44 | 36·5 | ·103 | 0·096 |
| 31·2 | ·153 | 2·88 | 35·6 | ·111 | 0·360 |
| 28·9 | ·177 | 5·76 | 37·1 | ·098 | 0·720 |
| 26·1 | ·210 | 11·52 | 34·5 | ·121 | 0·720 |

This series is in substantial agreement with the first series, showing that within these limits of pressure the coefficient does not vary with the pressure. The strain in the second series is about that of ordinary running belts.

### FOURTH SERIES.

Belt used, two inch wide leather belt with surface rather dry and polished by use. Hair side of belt to pulley.

Pulley used, ten inch iron; face, dry and well polished.

The chronographic speed record was taken in this and all subsequent series, and groups of observations were taken on various days. Temperatures and humidities were also observed, and although the groups on different days showed slight, constant differences from each other, yet no connection between these

differences and the humidity could be traced. There were in all about 180 experiments made.

The following table gives mean values taken from a curve drawn through a plot of those which were made with 100·8 pounds on the tight side of the belt. The maximum coefficient of friction of repose found in this series was 0·242.

| *Slip.* in. per m. | *f* | *Slip.* in. per m. | *f* | *Slip.* in. per m. | *f* |
|---|---|---|---|---|---|
| 1·5 | 0·192 | 40· | 0·291 | 500· | 0·572 |
| 2· | ·196 | 50· | ·301 | 550· | ·592 |
| 3· | ·203 | 75· | ·325 | 600· | ·611 |
| 4· | ·210 | 100· | ·347 | 650· | ·629 |
| 5· | ·217 | 150· | ·386 | 700· | ·646 |
| 6· | ·223 | 200· | ·420 | 750· | ·663 |
| 8· | ·233 | 250· | ·450 | 800· | ·679 |
| 10· | ·241 | 300· | ·478 | 850· | ·695 |
| 12· | ·247 | 350· | ·504 | 900· | ·711 |
| 15. | ·254 | 400· | ·528 | 950· | ·726 |
| 20· | ·264 | 450· | ·551 | 1,000· | ·741 |
| 30· | ·280 | | | | |

FIFTH AND SIXTH SERIES.

A subsequent series (fifth), of about fifty measurements in all, showed the same general variation of *f* with the rate of slip with loads of 50·8 pounds on the tight side of the belt, and all of the results showed a gradual diminution of coefficient for any given rate or slip as the belt became progressively more dry and polished from friction on the smooth pulley. This lessening amounted to nearly fifteen per cent. between the first group of experiments and the last one made, indicating thus the large change to which a belt may be subjected from wear in continual usage.

A series (sixth), with the same pulley and belt, but with the flesh side of the leather to the pulley, gave coefficients, substantially the same as the two series just referred to, but about fifteen per cent. lower than the average values obtained with the other surface of the belt.

SEVENTH SERIES.

Belt used, a four inch, soft, thick, clean leather belt, which had been used but was in good condition. Hair side to pulley.

Pulley, the same as in fourth series.

The group *m'* was the first one made with this belt, and will be seen to show a striking increase of *f* as the slip increases. The

group $m''$ immediately succeeded $m'$ and shows coefficients much larger than does $m'$ indicating an increasing coefficient of friction as the surface of the belt was more used. The measurements of a succeeding group agreed substantially with those of $m''$. Group $o$ was made under precisely the same conditions, except that the load on the tight side of the belt was $T = 101·3$ pounds instead of 51·3 pounds as in $m'$ and $m''$.

If these results be plotted, it will be seen that the resulting lines are much more convex upward than those for the fourth series, showing a much more rapid increase of $f$ at small rates of slip, and a less rapid one at high rates. This appears to result purely from the nature of the belt. Other kinds of belting would doubtless show materially different changes of $f$ with changing speed.

| SEVENTH SERIES. | | | | | | EIGHTH SERIES. | |
|---|---|---|---|---|---|---|---|
| Group m′. | | Group m″. | | Group o. | | Group q. | |
| *Slip.* in. per m. | $f$ | *Slip.* in. per m. | $f$ | *Slip.* in. per m. | $f$ | *Slip.* in. per m. | $f$ |
| 1·39 | 0·124 | 2·80 | 0·158 | 0·68 | 0·132 | 1·36 | 0·301 |
| 2·81 | ·130 | 2·80 | ·152 | 2·79 | ·145 | 2·80 | ·308 |
| 5·16 | ·144 | 1·36 | ·140 | 5·14 | ·164 | 5·14 | ·315 |
| 9·17 | ·165 | 5·16 | ·169 | 9·11 | ·188 | 9·11 | ·336 |
| 17·0 | ·195 | 9·15 | ·192 | 17·0 | ·233 | 16·9 | ·356 |
| 50·0 | ·274 | 17·0 | ·235 | 16·7 | ·233 | 16·9 | ·356 |
| 120· | ·387 | 48·6 | ·348 | 48·0 | ·263 | 31·3 | ·384 |
| 180· | ·435 | 48·0 | ·346 | 31·1 | ·315 | 50·0 | ·417 |
| 240· | ·508 | 120· | ·508 | 45·6 | ·357 | 120· | ·511 |
| 480· | ·600 | 240· | ·663 | 120· | ·580 | 180· | ·544 |
| 720· | ·625 | 480· | ·745 | 240· | ·725 | 240· | ·461 |
| 960· | ·748 | Repose | ·146 | 480· | ·793 | 480· | ·726 |
| $T = 51·3$ lbs. | | $T = 51·3$ lbs. | | 5·17 | ·169 | Repose | ·315 |
| | | | | Repose | ·163 | $T = 50·8$ lbs. | |
| | | | | $T = 101·3$ lbs. | | | |

EIGHTH SERIES.

To test somewhat the effect of lubrication, or of the oily condition into which belts often get in running, the two-inch belt used in the first and second series was soaked with sperm oil, and the pulley face was also thoroughly oiled. Two groups of measurements showed substantially accordant results, and one of them is given in the group $q$ in the table. A comparison of this group, or a plot from them, with the results of series first and second, will show that the coefficients $f$ for the group $q$ are much larger

than for these, and that the increase of $f$ as the rate of slip is greater is less in group $q$.

COMPARISON WITH RESULTS OF EXPERIMENTS BY OTHERS.

From the data given by Professor A. S. Kimball,* I deduce the following table. A comparison of this with my results will show that the increase which he finds in $f$ is even greater than any which I have found, but that the coefficients are on the whole much

| *Slip.* in. per m. | Rel. Coeff. of friction. | $f$ | *Slip.* in. per m. | Rel. Coeff. of friction. | $f$ |
|---|---|---|---|---|---|
| 0·37 | 0·42 | 0·264 | 15·4 | 0·78 | 0·491 |
| ·52 | ·44 | ·277 | 34·1 | ·86 | ·541 |
| 1·1 | ·48 | ·302 | 80·3 | ·96 | ·604 |
| 2·3 | ·53 | ·331 | 104·5 | ·99 | ·623 |
| 2·9 | ·55 | ·346 | 228·8 | 1·00 | ·629 |
| 4·4 | ·58 | ·365 | | | |

larger. He gives also the following table of relative coefficients (but without data sufficient for the computation of $f$) in which he finds a maximum of $f$ at a speed of 660 inches per minute and a diminishing value of $f$ at higher speeds. I find no such maximum

| *Slip.* in. per m. | Rel. Value. of $f$. | *Slip.* in. per m. | Rel. Value of $f$. |
|---|---|---|---|
| 18· | 0·82 | 1,190· | 0·96 |
| 92· | ·93 | 1,980· | ·82 |
| 660· | 1·00 | 2,969· | ·69 |

at speeds of slip up to 1,000 inches per minute, nor from my results is any such maximum indicated. This fact, however, does not, of course, in any way demonstrate or even indicate that there is not a maximum at high speeds. If there is, however, it must be beyond the range of the ordinary practice of belting.

Morin's experiments on the friction of leather belts, or iron pulleys, gave $f=0·28$ about. This result would correspond to a slow velocity of slip on the belts and pulleys used by me.

An examination of the statements, made by Mr. Towne† will show at once that his manner of obtaining uniform results, "By being careful that the final weight was such as to produce about the same velocity of the slipping belt in all experiments * * *" was a necessity solely from the reason that the coefficient of friction

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* A. S. Kimball. *American Journal of Science*, cxiii., 353, (1877).

† Towne. JOUR. FRANKLIN INST. lv. 89, (1868).

can have a given value at one velocity of slip, and at no other. It will also be seen, that in neglecting to make measurements at other velocities than that used (viz., 200 feet per minute), he overlooked the chief source of discrepancy between the results of various workers upon the subject, and obtained a result containing a purely arbitrary condition, viz., that of the velocity of slip at which his coefficient of friction was measured. The reasons why this high velocity gave good results, and why "it was found impossible to obtain any uniformity in the results when the attempt was made to ascertain the minimum weight, which would cause the belt to slip," are evidently these: First, for small velocities of slip, the coefficient of friction varies very widely for small actual differences in velocity—differences too small to be readily detected. Second, at high velocities the coefficient varies very slowly with change of velocity of slip. It is, of course, impossible to compare the experimental value $f = 0{\cdot}5853$ found by Towne with any result obtained by me, because there is no probability that the belts and pulley surfaces used, were at all the same in the two cases, and my results were not made at velocities above 1,000 inches per minute (83 feet). An inspection of my tables will, however, serve to show that, with all belts used, I have obtained values of $f$, both greater and smaller than that of Towne. The experiments of Mr. Towne, as is well known, were made by causing the belt to slip over a fixed pulley at a definite rate, and noting the weights used on the ends of the belt.

Mr. Edward Sawyer * finds the weight on the slack side, which will just suffice to stop the slip of the belt loaded with a constant weight at the other end and hung over a fixed pulley. He consequently finds coefficients much smaller than those of other observers, because the velocity of slip when the weight is finally adjusted is very small. He finds that "on polished cast iron pulleys, hard new leather belts require fully 75 pounds to hold 100 pounds; but usually the ratio is between 60 and 70 (slack side) per 100, corresponding to coefficient of friction from 0·17 to 0·12. Pieces of old belting, and thoroughly oiled, averaged better; some trials went as low as 56 per 100 ($f = 0{\cdot}19$). Rawhide belting appears to hold very well, giving an average a little

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* Sawyer. "*Proc. Soc. Arts*" Mass. Inst. Technology, Boston, 1881–82, p. 25.

over 60 per 100. Rubber belting averaged a little under 60 per 100." The method is, of course, open to the same line of criticism as that of Mr. Towne; for the coefficient determined was that corresponding to the slowest possible rate of slip, and the assumption of this as a standard rate, or as a rate at which the coefficient should be determined, is purely arbitrary. That this is the minimum coefficient is true, but that the use of the minimum coefficient will give the best results in practice is not proven. In point of fact, the coefficient which is actually in action in the average running belt is probably much larger than this. My own experiments also show me that the smallest coefficient obtainable from various belts does not correspond to the same rate of slip. Some belts begin to "stick" at higher rates than do others; and as the change of coefficient at these slow rates is very rapid, the assumption of the minimum observable coefficient made by Mr. Sawyer is doubly arbitrary.

My own experiments show clearly enough wherein one principal point of divergence between the various carefully devised rules for calculating belting lies. Some of these are based upon coefficients of friction derived from experiments at low rates of slip, some at medium rates, some at high rates, others are based directly on "good practice." If the same belt and pulley had been used by all the observers above quoted, each following his own method, the results would have been nearly as discordant as they now are. The question still remains, which is the best rule to follow? This I am not prepared to answer directly, for there remains an element still to be experimentally determined, viz., the rate of slip which exists in properly running belts on main and counter-shafts. That some slip, apart from the known "creep," always exists, can hardly be doubted. It is from measurements of the rate of this slip, which might easily be made by those having large and small belts running under suitable conditions, that further advance in the application of friction experiments to practice must come. The results will probably show that the coefficient to be adopted, depending necessarily on the slip to be allowed, must vary with the kind of work which the belt has to do. Apart from considerations as to the strength of the belt, it will be seen that a loose belt required to transmit an amount of power proportionate to its size, would slip upon the pulley at a gradually increasing

rate, until such a rate was attained that the coefficient of friction was large enough to maintain the requisite tension difference between the sides of the belt. If the belt were tighten a less difference in tension between the two sides would suffice to transmit the required power; therefore, the rate of slip and coefficient of friction brought into action would be smaller than before. If the belt were too loose, the slip would become abnormally large, either injuring the belt by excessive wear, or throwing it off the pulley. With too tight a belt on the other hand, the friction and flexure of the shaft become excessive. The size of the proper belt to be used for given work will be determined by these two limitations and that of avoiding an undue width of belt.

Since there is for any given belt so wide a variation in coefficient, which may be called into action as the slip changes slightly, it seems that exact computations will never be desirable in estimating the size of belting, and that the study of the laws of the friction of belts, at least on iron pulleys, will serve rather to give to the intelligent engineer a scientific guide to the limits within which the work of a belt of given size must be restricted, than to give him a fixed factor with which to compute the exact dimensions of a desired belt. The extension of such studies as the incomplete one which I have detailed to covered pulleys and under various other conditions, would doubtless develop many points of interest and value.

*Rogers Laboratory of Physics,*
MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
BOSTON, April 22, 1885.

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BITUMINIZED BRICKS.—Some of the streets of Berlin have been paved with bricks which were impregnated with bitumen. They are found capable of absorbing from fifteen to twenty per cent. of bitumen, and they then become remarkably elastic, tenacious and durable. It is hoped that the pavement will not only be found more durable than any other, but that the surface will also furnish a surer footing for horses.—*Les Mondes*, November 15, 1884.

OFFICE MUCILAGE.—Put 1,000 grains of potato starch into 12,000 grains of water, and add fifty grains of pure nitric acid; leave the whole in a warm place for forty-eight hours, stirring it frequently; then boil it until it becomes thick and translucid; dilute, if necessary, with water, and filter; also, dissolve 1,000 grains of gum arabic and 200 grains of sugar in 1,000 grains of water, add fifteen grains of nitric acid and boil. Mix the two products.—*Comptes Rendus*, November 15, 1884.

# On the JACKETING of WORKING CYLINDERS of STEAM ENGINES.

By A. S. Greene, C. E.

Among the various methods for increasing the efficiency of steam engines, and one that has been almost universally adopted, particularly in engines using large measures of expansion and in marine compound engines, is the system of steam jacketing the working cylinders. There are various ways of effecting this, but the most usual is to cast a cylinder somewhat larger than would otherwise be done and then to fit steam-tight within it, the smaller working cylinder, thus forming an annular space surrounding and extending its entire length, and to which steam of the boiler pressure and temperature may be constantly supplied. The cylinder heads are also cast with double shells, live steam being admitted to the space thus formed, so that the working cylinder is completely surrounded in all parts, with a space that can be supplied with steam of the highest pressure and temperature employed in the engine. By this means a part, at least, of the heat that would otherwise have been lost by the steam within the cylinder during expansion, is retained, or, more properly speaking, the heat lost by the expanding steam while performing work is partly restored by the abstraction of heat from the steam within the jacket. That only a part of the heat is thus restored is due to the fact that the cylinder shell opposes a certain amount of resistance to, and that a certain amount of time is necessary for, the transmission of the heat.

Of course, all the heat that is supplied to the expanding steam from the jacket must first be obtained from the original source, namely, the boiler; and the jacket being also subject to a further loss of heat from radiation from the exterior surfaces, it follows necessarily that the amount of effective heat for transmission into work by the medium of the jacket is much less than that drawn from the boiler to supply it. It is, in fact, a sort of "robbing Peter to pay Paul" process, with this disadvantage, that the amount received by Paul is very considerably less than that of which Peter has been robbed.

If it be really advantageous to reheat the expanding steam in the working cylinder, it would seem that some more rational and effective process, in which the resistance of the cylinder shell to the transmission of heat, and the loss from radiation, from the excess of exterior surface of the jacket over that of the actual working cylinder, would be avoided. This could easily be accomplished by supplying a small jet of steam from the main steam chest or steam pipe directly to the interior of the working cylinder, during the time of expansion, by means of suitably arranged and automatically operated valves. The ports for this purpose would necessarily be small; they need not be as large as the section of the pipe ordinarily used for supplying steam to the jacket, for the same amount of the heat supplied in this direct way would certainly effect a much greater amount of reheating than could possibly be done through the medium of the jacket.* If, as is generally believed, the loss of heat within the cylinder produces a condensation of the steam, which, instead of being deposited as water on the inner surface, remains as a kind of mist distributed throughout the interior, then certainly a jet of hot steam mingled directly with this mist must be more effective in reheating, and converting it into dry steam than the surface heating from the jacket.

The writer is well aware of the tenacity with which engineers, and particularly the builders of steam engines, cling to pet theories, especially after they have been so generally adopted in practice, and can readily understand that where profits are reckoned as a percentage of the labor and material employed in building machinery, the excess of these necessitated where the steam jacket is adopted, would be a powerful argument in its favor; but from an experience in the use of steam, extending over a period of more than twenty-five years, he has reached the clear and decided conclusion that there is nothing to be gained by the use of the steam jacket, or any equivalent, that can not be better and more rationally secured by other and more direct means.

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* The reader of this paper will find interesting matter relating to the admission of superheated steam to the cylinder in a paper on "Cylinder Condensation, Steam Jackets, Compound Engines and Superheated Steam, by George Basil Dixwell, Esq.," read before the *Society of Arts* of the Massachusetts Institute of Technology, Boston, April 29, and May 13, 1875.—Coleman Sellers, Prof. Mechanics, FRANKLIN INSTITUTE.

The steam engine being a machine for the transformation of heat into power, steam acting simply as a vehicle for carrying that power, the entire question, outside of mechanical details, is reduced to a question of heat. As it is axiomatic that a part cannot be equal to, or greater than, the whole, it is hard to understand how a part of a given quantity of heat can be made to yield more work than the whole of it, or that a given quantity of heat indirectly applied can be more effective than when it is directly applied; and yet this is exactly what is expected of the steam jacket, the jacket being supplied with a certain amount of heat only a part of which, it is well known, is to be effective within the cylinder, or in performing work. It is plain, that, of the heat supplied to the jacket, the loss due to the resistance to transmission through the shell of the cylinder, is a loss which does not obtain when the heat is supplied directly to the interior of the cylinder, and that the loss due to radiation from the exterior surfaces, which, though small compared to the total heat supplied to the jacket, must be vastly greater than that from the unjacketed cylinder, from the fact of the great excess of those surfaces, and the higher temperature constantly maintained beneath them. Again, the heat from the jacket, which is effective within the cylinder, must act in reëvaporating previously condensed steam, or in superheating, thus increasing the tension, and the steam of increased tension thus produced, is subject to losses of the same character within the cylinder, as if supplied directly from the main steam pipe at first, though the limits between which the losses occur may be different with the jacket from what they would be without it. Although the heat is constantly maintained in the whole jacket at all times, it can only be efficient in a part of the cylinder which is on one side of the piston, for, on the opposite side, it is communicated to the vacuum space and must be a dead loss for as great a time as it is a gain. Hence, the supposed gain attributed to the use of the jacket, it is believed, must be imaginary or due to some other cause.

It has been observed on several occasions, when running engines with the starting valve slightly open to one end of the cylinder to prevent thumping, that, although, during half the revolution communication was open directly to the condenser, causing a clear loss, the gain during the other half of the revolution was sufficient to appa-

rently compensate the loss, so that the revolutions were not reduced, nor the coal consumption materially increased; and this in one case with the low pressure cylinder of a compound engine, the valve being but slightly open and passing steam from the main steam pipe. A case is also remembered where a steam engine builder contracted with a mill owner to remodel an old engine and fit it for running his mill, for which he was to receive in payment the price of the coal saved in a certain time by the use of the remodelled engine, compared with that used by the engine of a rival builder running the same length of time.

The remodelled engine was carefully supplied with steam jackets, and with all the necessary accompaniments, but after a few weeks use, and, when it came to determining, by careful and accurate measurement, the quantity of coal consumed on which to base the payment, steam was carefully excluded from the jacket and air admitted instead, simply as a non-conductor to prevent loss of heat by radiation. It is needless to add that steam was not afterwards used in the jacket, and, notwithstanding this exclusion the engine continued to work with remarkable economy of fuel.

Whether there is any advantage to be derived from the use of the steam jacket or not, there are several disadvantages with which it is inevitably attended. There is extra material and labor required in the construction, and liability to loss of castings from their extra complicated nature, which cause extra first cost, besides extra weight and space occupied, together with the liability to cracking from unequal heating in getting under way, which are of special importance in the case of marine engines.

It is the writer's opinion that the best place to utilize the heat of steam in producing work is within the working cylinder, and not outside of it, preventing, as much as possible, the losses of heat, not by the use of the jacket, but with light sheet iron to inclose a corresponding space to contain air, which inclosure should be sufficiently tight to prevent circulation of the air and loss of heat from convection, and then carefully and thickly felted, and cased with wood outside of that. With the cylinder properly clothed, it is believed, better results would be obtained than by the use of the jacket, and certainly many extra pipes, valves, traps, and much annoyance, would be avoided.

*Philadelphia, May, 1885.*

# FLORIDA SUGAR.

BY OTTO LUTHY.

[*Abstract of remarks made at the Stated Meeting of the* FRANKLIN INSTITUTE, *June 17, 1885.*]

It will be of interest to many of the members of the FRANKLIN INSTITUTE to hear of the progress made in reclaiming the swamps and overflowed lands of Florida, by the Okeechobee Land Company, generally known as the Disston Enterprise.

I am not in the position now to dwell on the engineering achievements of this great enterprise. Hoping that the chief engineer of that company, Mr. J. M. Kreamer, will favor us sometime with a detailed description of his successful operations, I shall restrict myself to mention, that by the removal of obstructions, by the enlargement of natural waterways, and by the construction of drainage canals, a reduction of several feet of the water level of the Okeechobee Lake has been effected, and so far about 1,125,000 of acres of heretofore submerged land have been reclaimed, which, by the improved waterways, may now be reached 250 miles inland, by steamboats from the Gulf of Mexico.

The soil of this bottom land is a homogeneous heavy rich loam, largely composed of humus in depths varying from three to ten feet, and well fit for immediate cultivation.

It is easily understood in these times of continuous agitation of the sugar question, and when the Department of Agriculture in Washington encourages the farmers of all latitudes to produce the sugar the country now imports, that, with the extraordinary favorable condition offered by the Florida climate, the experiments of raising sugar should at once be made upon these fertile bottom lands.

I have the pleasure to-night to exhibit samples of the first sugar and molasses manufactured from cane grown upon these recovered lands, which were sent to me a few days ago, and which indicate a highly encouraging prospect for the sugar industry of that peninsulas

I report the following statements regarding these samples:

The sugar farm, on which the cane was raised, is located near Southport at the foot of Lake Tohopekaliga, about fourteen mile.

from Kissimmee City. Previous to the operations of the Okeechobee Drainage Company, it had been permanently covered with from two to three feet of water. The canal draining these lands was completed in February, 1883. In January, 1884, active operations were begun in clearing the reclaimed lands. Plowing immediately followed, and between February 14 and 20, 1884, the cane was planted, *one year subsequent to completing the drainage canal.*

The season has been unfavorable—a very dry spring and a very wet fall. The yield is, however, enormous, the stand perfect and the average length of cane fully matured twelve feet, many stalks measuring fifteen feet; average diameter of cane, one-and-three-fourths inches.

The harvesting of the crop was delayed till April 23, 1885, at which time the cane was still in perfect condition and growing; *five months* after all cane in Louisiana had been killed by frost.

These samples of sugar and syrup were made from *growing cane* (planted February 20, 1884,) on May 12, 1885. The juice then having a density of 9° B.; the grinding season thus lasting from December to May.

The apparatus for extracting the sugar was of a very imperfect and primitive kind, involving a loss of at least fifteen per cent. of juice in the "bagasse." No defecation or clarifying was attempted, and no addition made of any kind. With proper apparatus, the yield could be made fully twenty per cent. greater.

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| Average number of cane stalks per acre, , . . . . . . . | 16,000 |
| Gallons of juice obtained per acre, . . . . . . . . . . | 4,000 |
| Gallons of syrup, . . . . . . . . . . . . . . . . . . | 700 |
| Which, being sold at 40 cents per gallon, brought . . . . | $280 |

The cost to clear the land, fence and ditch it, seed cane, planting and cultivation, including all expenses up to grinding, was less than $100 per acre.

The present crop "ratoons" are remarkably fine, being far superior to the "plant" cane at the same season last year (June, 1884,) while the number of stalks per acre is fully double last season's crop. The crop will be at least seventy-five per cent. heavier than last year.

With a view of ascertaining the value of these new Florida products in the northern markets, I have made an analysis of the samples, which turned out as follows:

SUGAR:

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| Crystallizable, or cane sugar proper, | 96·4 |
| Uncrystallizable, or invert sugar, | 0·3 |
| Ash, | 0·5 |
| Moisture, | 1·7 |
| Organic non-sugar by difference, | 1·1 |
| Total, | 100·0 |

MOLASSES:

Density, 39° Beaumé = 1·362.
One United States gallon (231 cubic inches), weighs 11½ pounds.

| | |
|---|---|
| Cane sugar, | 53·5 per cent. |
| Invert sugar, | 12·2 " " |

The sugar at once manifests itself as a very high grade raw sugar, and with improved machinery and rational working could be made of such good appearance and fine aromatic flavor, that it would readily sell for direct consumption. As it is, it is worth here about five-and-one-half to six cents, wholesale. The syrup equals the best New Orleans molasses and would bring, perhaps, from fifty to fifty-three cents per gallon, wholesale, in this city.

These results certainly justify further experiments on the largest practical scale, and we may expect to hear soon of the erection of a large central factory to work up in a rational manner the cane produced by a cluster of sugar farms.

*Philadelphia, 220 Church Street, June 17, 1885.*

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CHLOROPHYLL AND ITS COMBINATIONS.—Some investigations of M. Guignet seem to show that chlorophyll is contained in envelopes, which are insoluble in petroleum ether, but soluble in alcohol. In pouring a solution by concentrated alcohol upon water, the chlorophyll is gradually precipitated by diffusion, but it takes the form of brown flakes, which appear completely changed. On replacing the water by alcohol at 50° the chlorophyll is precipitated in deep green flakes without any evidence of crystallization; but the product thus obtained is very impure. Chlorophyll is very stable in the presence of bases, behaving like a true acid and giving compounds which appear to be very well defined. In order to obtain in the crystalline state the combination of chlorophyll and soda, alcohol may be added to the aqueous solution of that compound. On evaporating over lime under a bell glass, water vapor is absorbed and the alcohol more and more concentrated until it deposits needles of a very deep green, which appear almost black. These needles are very soluble in water and present all the characters of a perfectly definite compound.—*Comptes Rendus*, February 16, 1885.

# THE METALLURGY OF STEEL.

BY PEDRO G. SALOM.

[*A Lecture delivered before the* FRANKLIN INSTITUTE, *February 25, 1885.*]

LADIES AND GENTLEMEN:—The Metallurgy of Steel is such a comprehensive subject, that it is impossible in one brief hour to give you more than the most general outline. It shall be my endeavor, therefore, this evening, to give you, first, a short sketch of the history of steel; second, a description of the three general processes employed in its manufacture; third, a description of the physical qualities of the various steels; fourth, their chemical constitutions; and, finally, some information of a statistical character that will give you some idea of the gigantic magnitude and vast importance of the steel industry.

There is still a great diversity of opinion as to what should be the proper definition of steel, and our learned doctors disagree on this as on every other subject. But the meaning of words, like plants and animals, develops, becoming more comprehensive, heterogeneous—or obsolete—restricted, as the case may be. It is certain that the old idea of steel, viz., a metal that could be hardened or tempered, as it is called, so as to resist the action of a file, has been greatly modified, as only a small fraction of the metal that is manufactured and known in the arts as steel, possesses such qualities. We may say in general, therefore, that all iron that has been melted and then cast into a malleable bar or ingot is steel. This excludes on the one side pig iron, which, although cast from a molten condition, is not malleable, and on the other side wrought iron, which, although malleable, has not been *melted and cast.* It should be observed, however, that the line of demarcation cannot be sharply drawn, for low carbon steel is simply homogeneous iron, possessing about the same physical characteristics as wrought iron, and white pig iron, or chilled iron, is simply high carbon steel. Whatever difficulty the public may have in explaining these apparent inconsistencies, and distinguishing these fine distinctions, there is little trouble among manufacturers who are familiar with the characteristics of the various steels.

The early history of steel is involved in obscurity, but it is tolerably well established that iron in various forms was known from 1500 to 3000 years B. C. The first iron used was undoubtedly of meteoric origin, as both the Greek and Egyptian names of that metal indicate. Iron is said to have been discovered by the burning of the forests of Mt. Ida, an accident somewhat similar to the one by which the Phœnicians are said to have discovered glass.

All the ancient writers of note, Diodorus, Pliny, Herodotus and Aristotle, mention iron and steel in their writings. The Egyptians must have been familiar with steel, as the inscriptions on the obelisks could only have been made with hard steel. The Phœnicians introduced the art into Greece, and from thence it passed into the Western world through the Roman Empire.

The development of the steel industry in England up to 1855 was exceedingly slow and insignificant, the old and primitive methods were still in use, and the total production of the United Kingdom in 1854 was only 40,000 tons, an amount (of a different grade, however,) which several establishments in this country can now produce in from ten to twelve weeks. The steel made was used almost exclusively for cutting tools, and was made in various ways, by immersing bar iron into molten cast iron, by direct reduction from the ores, like the old Catalonian process and by the cementation process, melting iron in a closed crucible with finely pulverized charcoal. But there was no process that could be employed on a commercial scale until about 1740, when, after the most laborious investigations extending over long periods of time, during which he failed again and again to accomplish his object only to renew his researches with greater zeal, Benjamin Huntsman was finally rewarded by the discovery of the crucible process, which, with slight modifications, is still used to the present day. At this time consumers of steel were compelled to pay the almost fabulous price of five guineas, or $25 per pound, and when we pause for an instant to consider the fact that steel rails can now be made for about $25 per ton, it is evident what strides have been made in perfecting the processes of steel manufacture.

To give a detailed description of the various methods that have been tried to produce steel, would consume the balance of our time. Suffice it to say that the most absurd means have been used in chemical reagents without regard to their action, or what was

expected to be accomplished. Various oxides and alloys, sal-ammoniac, soda, potash, borax, alum, glass, salt, burnt horse-hoof, lime, magnesia, tar, and a hundred other nostrums have been patented, but those only of commercial importance are the oxides and carburets of manganese, about which we shall speak later in describing the crucible and Bessemer processes. Even electricity was called upon to exercise some of its marvels upon iron, and thereby produce a superior steel.

CRUCIBLE PROCESS.—We come now to the consideration of the three general processes used in the manufacture of steel, and the first in point of time, is the crucible process, which, until the advent of the Bessemer, was by far the most important method of making steel. (*Plate I.*)

In the crucible process, as practised at the present time, the material to be melted is first packed in the pots. This is done by weighing out in pans the scrap and blister steel, or whatever other material is used, depending upon the nature of the steel desired. About eighty pounds of this material are carefully packed in crucibles usually made of black lead. (It was formerly the custom to place the pots on a preparatory annealing grate, where they could get red hot; then transfer them to the furnace, and heat them to a white heat before putting in the charge, which was done by means of a funnel; but to charge a pot in a white-hot furnace in this manner was exceedingly awkward, as can readily be imagined.) The heat having been brought up to the melting point, the lids are placed on the pots, the covers taken off the holes, and the pots placed on little stands in the shape of truncated cones, made of fire clay or old crucible bottoms. The melter has no trouble from this time except that of seeing that his furnace is kept sufficiently hot to melt the steel. When coal or coke is used as fuel, instead of the regenerative gas system, far more attention is required of the melter to keep his furnace in proper condition.

While the melting is going on, preparations for the next heat must be made, which consist of cleaning the old pots from a previous heat (sometimes these pots last six or seven heats) weighing out the steel scraps and packing them as before.

The moulds also have to be in readiness to take the "heat" already in the furnace. They are generally made in two long, flat, rectangular bars, which, when placed together, form a space

the size of the desired ingot. They are fastened with rings slipped over the top, and held in place by driving wedges between them and the sides of the moulds. The moulds are carefully wiped, and then smoked by burning tar or pitch under them, with their face downwards; this is done in order to prevent the steel from sticking to them.

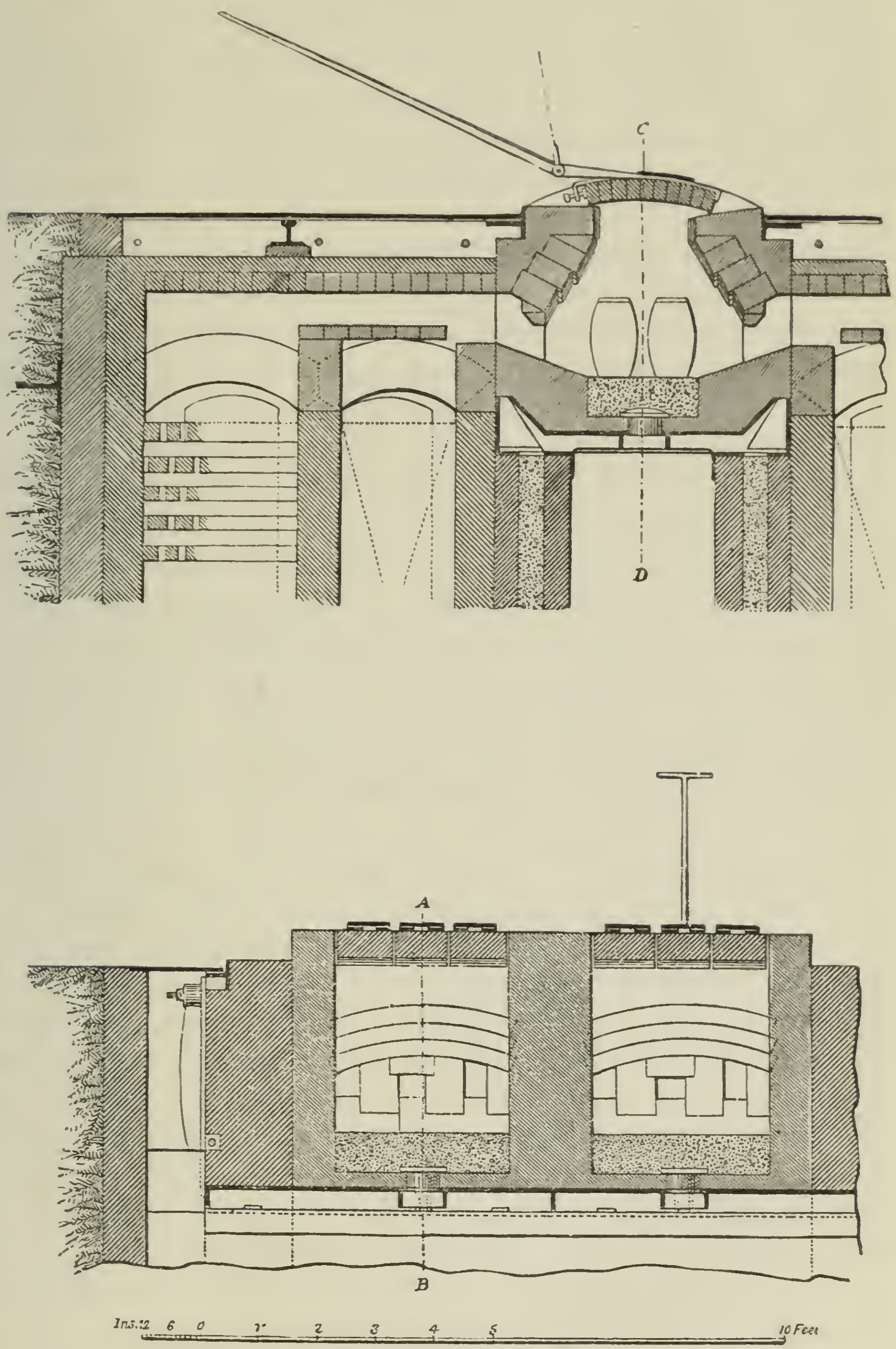
The melter now ascertains if everything is melted in the pots by moving the lid a little to one side, with a long iron bar or poker, and then stirring the contents of the pot with the same or a similar bar. This can also generally be ascertained by reason of the fact that, so long as the steel is not all melted, the contents of the pot appear to be in a state of ebullition, but when the steel is all melted, or "killed," the metal is as liquid as mercury, and "resembles, in its dazzling brilliancy, the sun." Everything being in readiness, the melter, or "puller out," having previously prepared himself by wrapping old pieces of carpet and sack-cloth around his waist and legs and over his feet, and placing a thick glove or mitt, extending almost to the shoulder, on his right hand, saturates his wraps with water, seizes a bell-shaped pair of tongs, and, the cover having been removed from the furnace, he places the tongs over and around the crucible, moves the pot slightly to loosen it from its fire-clay stand, and then, with a quick motion, stoops down, grasps the tongs lower down, near the pot, with his protected hand, and in rising brings the pot up with him, and with a swinging motion places it wherever desired. No more grotesque sight could be imagined than to see a number of those men, with their clumsy paraphernalia, moving around the furnace floor and taking the pots from the furnace.

The puller out removes the lid from the crucible, and the pouring or "teeming" takes place at once, for the metal is not like pig iron and cannot be handled for any length of time without chilling. The pot is seized by another man with a peculiar shaped pair of tongs, and poured carefully into the moulds, while a third man stands over him with a long skimmer or rod bent at one end, and prevents any slag from passing into the moulds. The red-hot ingots can be knocked out of the moulds in a few minutes and then taken away to be hammered or rolled, as the case may be. In either case they are found to be defective or piped about one-third of the way down, and this defect is not removed by subsequent

rolling. By this method of melting, one ton of coal will make one ton of crucible steel ingots, whereas in the old coke system it required about three tons of coke per ton of ingots. The holes are now made to hold four, six, and even eight pots. The operation requires about four hours, and therefore six heats a day can be made. The work is very severe (especially in summer time) on the melter or puller out, on account of the intense heat, and only the toughest and strongest kind of men can stand it for any length of time. It seems almost incredible that Krupp makes his large cannon by this primitive process, yet nevertheless this is the case, but it is done with such military precision as to be a matter of little or no difficulty. For manufacturing one of his largest guns, about 1,800 crucibles are required, each containing about sixty pounds of steel.

THE BESSEMER PROCESS.—Is the greatest metallurgical discovery that was ever made, and dwarfs into insignificance all other methods of manufacturing steel. It not only has revolutionized the iron industry, but also the sister industries in which iron plays the most important part, and is declared by M. Chevalier to be of more value than the discoveries of all the gold fields of California and Australia. Moreover, it is safe to predict that—by a closer study of the chemical nature of steel, that notwithstanding the marvels it has accomplished in the past—it will accomplish even more remarkable results in the future. It is probable that all grades of steel from the hardest tool steel to the softest and most ductile boiler plate can and will be made by the Bessemer or pneumatic process.

The history of the Bessemer process is replete with all the trials and tribulations that all great inventions have to pass through before reaching the commercial stage. Only a man of the most magnificent courage and indomitable perseverance could have carried it through to a successful issue. The difficulties to be overcome were gigantic, and would have appalled a man of less strength and faith in his convictions. He spent thousands of dollars, built furnaces, only to tear them down and rebuild them again, with, perhaps, a new idea suggested by a previous failure. When he read his paper before the British Association in 1856, after several years of laborious experiments, he was ridiculed by most of the metallurgical savants of England. They insisted: (1), that he could not accomplish what he claimed, (2), that even




MODERN CRUCIBLE FURNACE.

though he did accomplish his object the resulting product would be of no use, and (3), that, after all, it was no new discovery and that all the facts in the case were well-known and had been known for years. The Industrial Press criticised the process in the most satirical style, and after a few unsuccessful attempts had been made by iron founders, the process was abandoned, and declared a failure and a fraud. Two more years of unceasing toil and anxiety and $80,000 were expended. His best friends tried to dissuade him from pursuing any further an investigation which had commenced to tell on his health, and which leading engineers had pronounced chimerical. But genius and perseverance finally conquered, and he was able to produce a metal worth from $250 to $300 a ton from pig iron which only cost $35 per ton, by simply forcing atmospheric air through it for fifteen minutes. Jeans says: *

"It is not at all surprising that the Bessemer process, on its first announcement, evoked expressions of incredulity and scorn. Pure malleable iron in a fluid state was then wholly unknown in commerce. Even its exposure for several days in the hottest furnaces then in use failed to bring malleable iron into a state of fusion, while Bessemer proposed to convert ordinary melted cast iron into this malleable fluid state in quantities of not less than five tons, in the short space of fifteen minutes, by the mere action of cold atmospheric air, and without any coal or other fuel except that which the crude iron itself contained in the form of combined carbon. * * * * * * * * *
Thus was the so-called fallacious dream of the enthusiast realized to its fullest extent, and it was now his turn to triumph over those who had so confidently predicted his failure. He could now see in his mind's eye at a glance, the great iron industry of the world crumbling away under the irresistible force of the facts he had elicited. In that one result a sentence had gone forth which not all the talent accumulated during the former 150 years, of the many thousands whose ingenuity and skill had helped to build up the mighty fabric of the British iron trade—no, nor the millions that had been invested in carrying out the then existing system of manufacture, with all its accompanying powerful resistance, could reverse."

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* "Steel: Its History, Manufacture and Uses;" p. 65. By J. S. Jeans.

The vessel in which the operation is conducted is called a converter, and consists of three parts, the dome or hood, the body or belly, and the bottom. These parts are usually made of wrought iron or steel plates, about one-half inch thick, and are bolted together by means of strong cast iron angle collars above and below. The body is also surrounded and firmly secured to a cast iron or steel belt or hoop, bearing the trunnions on which the converter revolves. One of the trunnions is solid and is connected with a spur wheel which is acted upon by a rack attached to the piston of an hydraulic cylinder. The other trunnion is hollow and is connected with the blast pipe by means of a stuffing box. The tuyere box (a flat cylinder made of iron or steel plate) and bottom are perforated with as many holes as there are tuyeres, and are bolted together, after the tuyeres, which are made of fire clay, have been securely luted in their places. The tuyeres are truncated cones and are pierced with from five to fifteen holes, varying from three-eighths to one-half inch in diameter, according to the size of the converter and the works. Their length is such that they are flush with the lining of the converter. The lining is made of gannister from six to twelve inches thick, tightly rammed between the shell of the converter and a wooden mould. The lining will stand as many as 1,200 blows, but the bottom and tuyeres wear out much quicker.

The pressure of blast varies from ten to twenty-five pounds per square inch, while the blast jets vary in number from 49 to 189. The ordinary converters of three or four tons receive the blast by forty-nine holes of one-half-inch diameter. In England and Belgium, the converters from five to seven tons have eleven tuyeres, with seven holes of five-twelfths-inch diameter. In the United States, eleven tuyeres are also employed, but generally with twelve holes.

One of the most important features of a converter is the facility with which the bottoms and tuyeres can be renewed when worn out, and their powers to resist such a high temperature as the converter is called upon to sustain, and it is probably due to the superior mechanical arrangements in American Bessemer works that enables them to make such a large output with a plant so comparatively small. Five hundred or 600 tons of steel are made regularly every day with only two converters.

*Bessemer Bottoms.*—The plan finally adopted, and now used almost without exception in America, and to some extent elsewhere, has a duplicate bottom, so constructed as to leave the annular space between it and the wall of the vessel open to the exterior of the vessel, so that a workman standing outside can ram the annular space, and thus make a sound joint without saturating it with water, and while the interior of the vessel is still red hot.

The worn bottom being removed by a hydraulic lift, or by any convenient means, the new one is inserted at once, and the annular space is quickly rammed with plastic cakes of gannister, thus making the lining continuous and solid. Sometimes a part of the wall of the vessel comes away with the bottom, and sometimes part of the bottom sticks to the wall of the vessel. The annular space is thus left so irregular that merely luting the new bottom and pressing it up could not make a good joint; but when all these irregular cavities are seen and filled from the outside, the joint is always sound.

*Cupolas.*—One of the important adjuncts of a Bessemer plant is the cupola for melting the pig iron. The cupola generally employed in American Bessemer works melts 100 tons in eighteen to twenty hours. The work required of it differs from a foundry cupola. It must deliver six tons an hour, at the highest attainable temperature, for a whole day and night. There must be a deep hearth or receptacle for slag under the tuyeres, and an upper tapping hole, by which the slag may be worked off, as in a blast furnace. The tuyere area must be excessively large, to insure ample air admission in case of partial chilling at any point, and the size, shape, and arrangement of the tuyeres must be such that they can be readily cleaned and changed without stopping the operation.

A cupola for a five-ton plant is of five feet internal diameter and fourteen feet high; it has six oval tuyeres of five and eight-inch diameter.

The blower used with the greatest success is the Sturtevant high speed fan blower.

Interposing ladles between the cupolas and converters are of service in many respects; the weighing of the charge is accomplished by this means.

In the best practice, 160 pounds of coke will melt one ton of iron.

The spiegeleisen is usually melted in a smaller cupola.

*Cranes.*—The cranes in a Bessemer plant are always hydraulic, constructed in a very simple manner, and do the required work with great ease and rapidity. The ladle crane is also an hydraulic crane and the ladle can be moved up or down and in or out without difficulty.

The hydraulic cranes used in Bessemer works consist of a vertically moving ram, to which a horizontal jib is attached. In ordinary cranes the jib does not move vertically, which is a serious comparative disadvantage, because all radial transference of the load must be done by racking the jib carriage, from which the load is suspended backwards and forwards by slow moving gearing or pulleys. When a jib rises and falls, its carriage may be moved radially by simply pushing the load. The carriage runs on the jib just like a car on a railway unhampered by sheaves and chains.

*Ladles.*—The ladles usually employed for casting Bessemer steel are constructed of boiler plate, lined with refractory sand, and furnished with a strong belt in cast or wrought iron, either made in a single piece and bearing two trunnions, which rest upon the arm or jib of the crane, or composed of two pieces bolted together. In the bottom of the ladle an opening is made both through the plate iron and the lining for the tapping hole.

The tapping hole is closed with an iron bar wrapped with clay and with a black lead stopper on the lower end, which is made to accurately fit the nozzle inserted in the bottom of the ladle. The other end is a goose neck, fastened to a casting attached to a sliding bar worked by a lever. By raising or lowering the lever the stopper is raised or lowered and the flow of the metal can be discontinued instantaneously, or regulated at will.

*Ingot Moulds.*—Ingot moulds are among the accessory appliances required for the Bessemer process. The best moulds are those where the thickness is so adjusted that the expansion is equal.

*Hydraulic Regulators.*—The hydraulic regulators are so arranged, that one or two boys by simply moving levers can keep all the cranes moving and regulate the motions of the converters.*

Tchernoff's description of the Bessemer process in the "Pro-

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* Abridged from J. S. Jeans' "Steel: Its History," etc.

# BESSEMER PLANT.

## FIVE TONS OSCILLATING CONVERTER.

Fig. 2.

Section A. B.

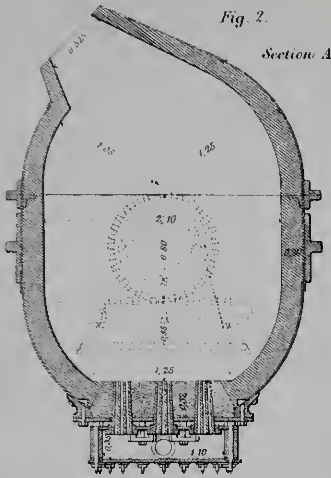



Fig. 1.

Elevation

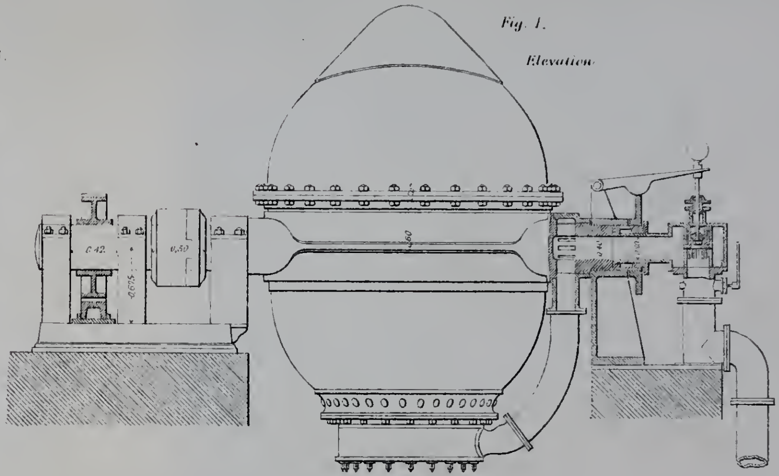



Fig 4.

Tuyere Box

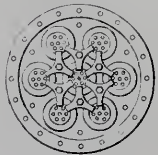
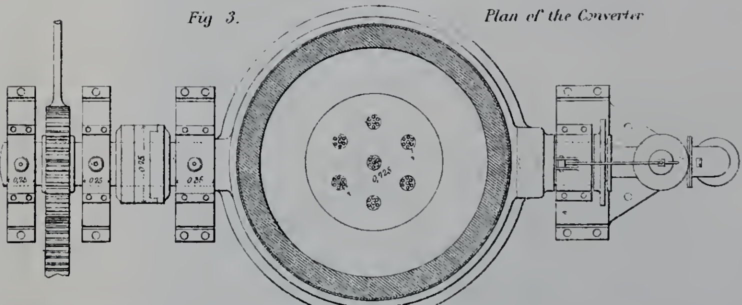


Fig 3.

Plan of the Converter




Scale of Metres

ceedings of the Imperial Russian Technical Society," is so admirable, that I quote it almost in its entirety:

*Description of Process.*—In the Bessemer process, the retort previously heated is put into a horizontal position. Pig iron is then run in, coming by a channel from a cupola or reverberatory furnace, or in some places brought in ladles direct from the blast furnace. The apparatus being constructed for producing five tons of metal, the charge will occupy only a tenth part of the cubical contents of the converter. The pig iron being introduced, the blast is put on, and the converter brought back to the vertical position. As the pig iron reaches the tuyeres, it encounters the blast, which not only prevents it from entering the openings, but also forces its way through the mass of liquid metal with great violence, the pressure of the blast being seven times greater than that of the column of metal. At this moment the combustion of certain constituent elements of the pig iron begins. The gaseous products of this combustion are vomited forth from the neck of the converter into a chimney, while the impurities are thrown off from the metal, which, at the end of the operation, is almost pure iron. The amount of heat developed by this combustion is so considerable that, in spite of the progressive diminution of the fusibility of the charge, it remains as liquid as mercury. In this reaction, which lasts about twenty minutes, we may distinguish four periods. (*Plate II.*)

*First Period.*—As soon as the blast is put on we see, coming out of the neck of the retort, a feeble flame, conical in shape, of a yellowish red tint, and accompanied by an abundant shower of sparks. At the same time there is produced in the interior of the converter a noise similar to that which would result from blowing air into an empty vessel. After a few minutes this noise seems to issue from the neck only, where it localizes itself towards the end; the flame begins to turn blue and elongates, assuming the form of a cone and becoming brilliant. The sparks are then finer and less abundant. The blast forces itself more easily through the charge on account of its increasing liquidity, which permits an increase in the speed of the blowing engine, giving a longer volume of blast.

*Second Period.*—These phenomena characterize the approach of the second period. The change occurs suddenly, and a person

who observes for the first time the progress of the operation can easily note a very apparent alteration in the flame and the sound. This period lasts from two to four minutes without apparent change.

*Third Period.*—The transition to the third period is not so marked as that from the first to the second. In the course of this phase of the operation the sound increases, the length of the flame diminishes to fifteen or twenty feet, and its brightness is so intense that it becomes dazzling to the eye. As these changes in the flame occur the charge boils over in splashes of fluid slag. These splashes are sometimes so abundant and are discharged with such violence, that the shower of sparks spreads over a radius of several yards. Two or three minutes afterwards the discharges cease and the reaction continues without any apparent change in the flame or the sound. The duration of this period is nearly the same as that of the first.

*Fourth Period.*—The fourth period marks the end of the operation. The flame contracts and the sound diminishes abruptly. This period lasts but a few seconds, and if the admission of the blast is continued the reaction seems to assume again the characteristics of the first period. The flame disappears almost completely, the sound is diminished, the luminous cone reappears—with this difference, however, that in place of the shower of sparks of the first period an enormous quantity of reddish smoke is produced. The fourth period lasts from five to ten seconds, and terminates the process. The converter is returned to the horizontal position the blast is shut off and a certain quantity of spiegel iron rich in carbon and manganese is added to the charge, which gives to the liquid iron the quantity of carbon necessary for its transformation into steel, and by the reaction of the manganese frees the charge of the oxide of iron which impregnates it."

*Gaseous Products.*—The composition of the gaseous products of a converter in the different periods of a blow have been determined with as much accuracy as the difficulties attending such determinations would permit. These analyses show that at the beginning of a blow the gases are composed of nitrogen carbonic acid and free oxygen; next toward the second period the gases take up carbonic oxide in rapidly increasing quantities and hydrogen appears and remains constant to the end of the operation. The

presence of hydrogen is explained by the humidity of the blast. If not in the gases at the first period, it is probable that at the commencement of the blow it is absorbed by the metal in fusion.

The composition of the gases disengaged during the different periods of the operation, explains to us perfectly the external phenomena visible in the flame. Thus in the first period, the gases containing no combustible element, there is no noise; nor can the flame be long as everything is already burned. We see only the incandescent products of combustion. In the second period, a large quantity of carbonous oxide is escaping and is consumed at the expense of the oxygen of the external air, which occasions the noise. The flame assumes the shape of a cone, similar to the luminous part of a candle flame. In the third period, the volume of the gases exceeds in quantity the air introduced through the tuyeres. Finally, in the fourth period, the impoverishment of the combustible gases, diminishes the noise and shortens the flame.

*Conversion of the Pig Iron.*—The study of the conversion of the pig iron in the Bessemer converter shows that it is simply a refining process analogous to puddling. The following table will show this:

| | Pig. | End Second Period. | End Third Period. | End Fourth Period | Steel. |
|---|---|---|---|---|---|
| Graphite, . . . . . . . . . . | 3·180 | | | | |
| Carbon, . . . . . . . . . . . | ·750 | 2·645 | 0·949 | 0·087 | 0·234 |
| Silicon, . . . . . . . . . . . | 1·960 | ·443 | 0·112 | 0·028 | 0·033 |
| Phosphorus, . . . . . . . . . | 0·040 | ·040 | 0·045 | 0·045 | 0·044 |
| Sulphur, . . . . . . . . . . | 0·018 | traces. | traces. | traces. | traces. |
| Manganese, . . . . . . . . . | 3·460 | 1·645 | 0·429 | 0·113 | 0·139 |
| Copper, . . . . . . . . . . . | 0·085 | 0·091 | 0·095 | 0·120 | 0·105 |

The spectroscope was used to great advantage in the early days of the Bessemer process, but the process has been brought down to such an exact science that it is no longer necessary. What I particularly desire to emphasize to-night, is, the great possibilities that still lie dormant in the Bessemer process.

Springing as it did, like the telegraph, full-fledged into existence with all its startling effects, it has, with the exception of some minor

mechanical details, remained just as it came from the inventor's hands. It was years before any great improvements were made in telegraphy, but the time came when all sorts of ingenious contrivances from the "stock ticker" to the "telephone" were offsprings of the great parent invention, and so it is with the Bessemer process, the side issues of this invention are just beginning to be realized, and the basic or Thomas-Gilchrist process and the Clapp-Griffiths process, are simply indications of the various valuable modifications of which this process is capable.

Open Hearth, or Siemens-Martin, Process.—We come now to the third and last general process for manufacturing steel, viz., the Open Hearth, or Siemens-Martin, process. (*Plate III.*)

The furnace usually employed in this process is a large, cumbersome mass of masonry and brick-work, bound above and below with old rails or bridge girders. The furnace proper is encased in heavy cast or wrought iron plates which are lined with fire-brick a foot or more in thickness, and in addition to this, a thick bed of sand is spread over the bottom, which is fused into one solid mass when the furnace gets its heat. The roof was formerly made to dip towards the centre from both ends but now in some of the best and largest furnaces it is simply a plain flat arch. It should be built of the most refractory brick that can be obtained; pure silica brick being usually employed for this purpose. The inside of the furnace and the air and gas ports are also lined with silica brick.

Below the furnace proper are the four regenerative chambers which are loosely filled with fire bricks (called the checquer work), in such a manner as not to impede the free circulation of air and gas through them. These chambers connect with the furnace through small passages, called the "ports," and with the gas producers and chimney through underground flues. The underground flues are so arranged in connection with valves, that the air and gas are admitted separately to the two chambers on one side of the furnace, pass through the chambers and into the furnace through the ports, where they are united on the hearth of the melting chamber, the waste products of combustion pass through the ports on the other side down through the chambers, giving up their heat to the checquer work and finally pass through the flues, out the chimney, comparatively cool. The current is reversed by means of the valves about every twenty minutes, and the incoming

gas and air are thus heated to a very high temperature before uniting, thereby increasing the intensity of combustion.

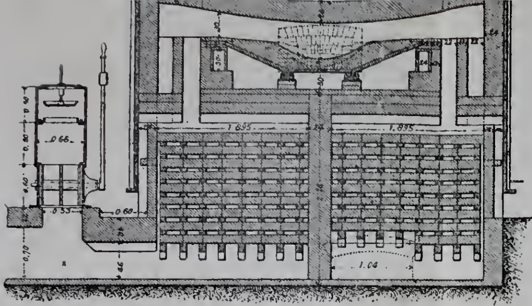
*Methods: Pig and Ore, and Scrap.*—There are two methods employed in making steel in the Open Hearth furnace. In the first method pig iron alone is melted and decarbonized with ore; in the second, besides the pig iron charged, wrought iron either in blooms or muck bar, and scrap, are used to reduce the carbon of the pig. In the pig and ore process, to the pig iron, after having been charged and melted (which requires four or five hours), pure iron ore is charged cold into the bath in quantities of 400 or 500 pounds, a violent ebullition takes place, and when this has abated, a new supply of ore is thrown in, the object being to keep up uniform ebullition as nearly as may be. Of course care is taken that the temperature of the furnace is maintained sufficient to keep the bath of metal and slag sufficiently fluid, but after the lapse of some time, when the ore is thoroughly heated and reduction is taking place rapidly, the gas may be in part shut off from the furnace, the combustion of the carbon in the bath itself keeping up the temperature. In the course of the operation the quantity of ore charged is gradually reduced and samples taken from time to time of both slag and metal, and when these are satisfactory, spiegeleisen or ferro-manganese, is added and the charge cast. This mode of working takes a little more time than the scrap process, and the consumption of fuel is rather larger. Starting an Open Hearth furnace requires much more time and labor than starting a converter.

The operation is commenced by building a fire in the producers, and when they have a sufficient body of red-hot coal, say from five to ten tons, the gas may be cautiously introduced into the furnace, which has been previously heated by burning wood and coal on the hearth. The introduction of the gas into the furnace is often attended with considerable difficulty and danger, for if the pressure is relaxed for an instant, or there is a back draught, there is sure to be an explosion or "kick," as it is generally termed. This is caused by the air not being all expelled from the gas chamber, an explosive mixture of gas and air resulting. Sometimes these explosions destroy the flues and break the arches of the regenerators, necessitating a stoppage of several hours or even days. Soon after the admission of the gas, the furnace begins to heat up very rapidly, and after reversing a few times, begins to get

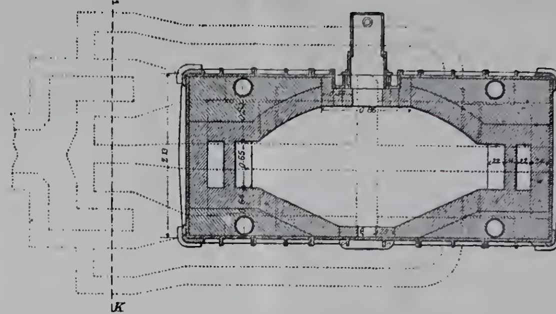
red hot. In a large (fifteen ton) furnace, it takes about twenty-four hours, before the melter can begin to make bottom. This is done by shovelling in sand, which soon sets at a white heat and closes up all the cracks made by the expansion at the beginning of the operation.

As soon as the bottom sets, the melter is ready to make the charge, which is generally conveyed to the furnace floor some ten or twelve feet above the ground by means of an hydraulic elevator.

The charge consists (supposing we are making a boiler-plate heat of fifteen tons) of about 5,000 pounds pig iron which forms the initial bath. To this, after being melted, is added about 10,000 pounds of scrap, in the shape of furnace scrap from the previous heat and the shearings from rolled plates. When this has partially melted, 15,000 pounds of the best Bessemer muck bar or charcoal blooms are charged in several thousand pound lots, so as not to chill off the furnace too much. It was formerly the custom (and is still in some places) to preheat all this material before it was charged into the furnace, but now it can all be charged cold without any inconvenience. The melting requires between five and six hours, and sometimes even longer. When the heat is completely melted, which is ascertained by the melter putting a long iron hook into the bath and moving it around, the bath is well stirred and a sample taken out for inspection or analysis. The melter can tell from this sample whether it is necessary or not to decarbonize by the further addition of blooms or muck bar and, when ready, the amount of the final additions to be added, which consists of about 150 pounds of a very high manganese pig iron (containing about eighty per cent. manganese) known in the arts as ferro-manganese. As soon as the ferro-manganese is added and the bath is stirred or rabbled vigorously, the heat should be taken out immediately, for if it is allowed to remain in the furnace the oxidation continues and the metal is injured. While the charging has been going on, preparations have been made in the pit and floor for receiving the metal. A large number of ingot moulds are placed on the "group plates" with a central runner, on top of which is a fountain all lined with fire-brick or clay. When everything is in readiness, the ladle, which is made of heavy iron plate riveted and lined with fire-brick, and which has been heated red

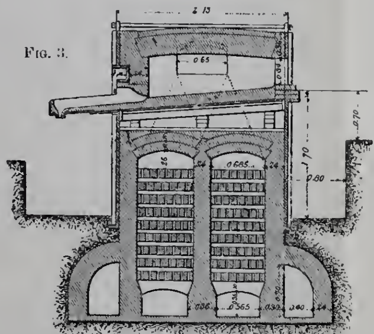



Section at A B, C D.



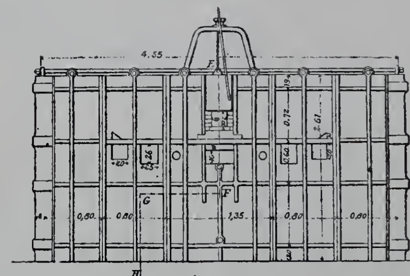

Plan.

Fig. 3.




Section at E F, G H.

Fig. 4.




Charging Side.

Fig. 5.

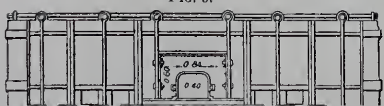



Fig. 6.

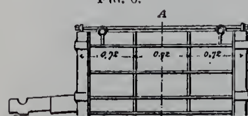
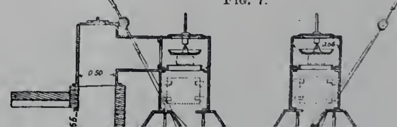



Fig. 7.



hot, is brought under the spout and a heavy iron tapping bar is driven into the furnace by means of a ram. The metal comes out with a rush and with a dazzling brillancy, scattering thousands of sparks over everything. The sight at night is a very beautiful one, although not equalling the Bessemer. When the charge has all run out of the furnace, the ladle is brought over the fountain on top of the runner, the stopper raised, and the metal, passing down the central runner, radiates in several directions, and runs into the ingot moulds from below, gradually filling them to any desired height. This is called bottom pouring and insures a much better ingot than by merely pouring the metal in the top of each mould. The tapping-hole is closed again and, the bottom having been repaired, is ready for another charge. The whole operation can be completed in seven or eight hours, thus enabling the production of three heats a day, the operation being continuous.

*Pernot.*—Some of the Open Hearth furnaces are constructed with a movable or revolving hearth, and they are then known as the Pernot furnace. They diminish the time required for melting, but they are much more costly and are exceedingly difficult to keep in good working order.

An Open Hearth plant, while not so expensive to construct as a Bessemer, is far more costly to operate, owing to the relatively small production and the difficulty and time consumed in repairs, and the necessity of using iron in some refined shape, either as muck bar or charcoal blooms, which are very expensive. The quality of the steel, however, can as yet be made far superior to that of the Bessemer.

THE PHYSICAL QUALITIES OF STEEL.—There are few subjects that have been so carefully studied as that of the physical nature of steel. The most elaborate investigations and costly experiments have been made, and although our knowledge has become considerably enhanced by the results obtained, still not nearly so much has been accomplished as these elaborate experiments would seem to indicate, and we are still in lamentable ignorance.

When a bar of steel is placed in a testing machine, constructed for the purpose and actually pulled apart, there are four physical qualities which may be observed.

(1.) Tensile strength or the weight per square inch, required to break the bar.

(2.) Elongation or ductility or the amount the bar has stretched between two given points.

(3.) Elastic limit, or the weight per square inch that can be applied without giving the bar a permanent set.

(4.) Reduction of area, or the area at the point of fracture compared with the original area.

The tensile strength and elongation are the important elements, while the elastic limit and reduction of area are a complement or corollary of the first two.

The tensile strength of steel varies from 50,000 to 200,000 pounds per square inch, and with it, of course, the other properties vary. No quality of steel is more readily affected by its composition and treatment than its tensile strength. For every employment for which steel is used, steels of various tensile strengths have been tried ; yet, notwithstanding the fulness of the information on this subject, engineers and manufacturers are still unable to agree in some cases as to the proper tensile strength to use.

The elongation or ductility of steel varies from nothing to thirty-three per cent. in an eight-inch section. It is the greater ductility of steel that renders it superior to the best iron in the construction of boilers, ship plates, fire boxes, etc.

The ductility of steel is in most cases its most valuable quality. Strength without ductility is of little value to the constructing engineer. Tool steel is very strong, but no one would recommend it for boilers. Something that will bend before breaking is the great desideratum. Then it is an easy matter to so proportion the structure that no portion of it shall have an undue load or strain. Some years ago the engineers of the Pennsylvania Railroad were surprised to find that some steel bridge rods had broken in service. Samples of the steel were sent to Altoona, and physical and chemical tests made. The result of the investigation proved the anomalous fact that the rods broke because they were too strong ; that is to say, the steel having a very high tensile strength (about 100,000 pounds) would not yield to slight inequalities of mechanical construction, and therefore the strain coming on a single point, broke the rods.

Had the rods been made of steel with a tensile strength of 60,000 pounds and fifteen or twenty per cent. elongation, they would have bent and thus allowed the strain to come on the whole rod instead of on a single point.

The elastic limit varies from 15,000 to over 100,000 pounds per square inch, while the reduction of area varies from nothing to seventy per cent.

The following table will show the physical characteristics of steel made for various purposes by the three methods described above:

| | Tensile S. | R. of Area. | Elongation in 2 inches. |
|---|---|---|---|
| American Tool Steel, | 129,000 | — | 12 per cent. |
| Bessemer Steel (for rails), | 81,000 | — | 17 " |
| Open Hearth Steel (for springs), | 143,000 | — | 6 " |
| Open Hearth Steel (for boilers), | 60,000 | 65 per cent. | 30 " (in 8 in.) |

The tensile strength of the best Sheffield tool steel is about 130,000 pounds.

Bessemer and Open Hearth steel can be made with tensile strengths, varying from 50,000 to 150,000 pounds.

The physical properties of a piece of steel are greatly influenced by the amount of "work" (rolling or forging) that has been expended upon it.

An interesting illustration of this fact was given by Mr. Hunt, in a paper read before the Engineers' Society of Western Pennsylvania. An ingot, twenty-four inches in diameter, was forged to sixteen inches and test pieces taken from disks, cut from the forging. A part of the forging was reduced to eight inches square and test pieces taken in like manner from it; another portion of the same material was rolled into a three eighths-inch plate, and test pieces taken from it. These test pieces were broken in the testing machine and all being of the same chemical constitution, viz: Carbon, 0·28; manganese, 0·60, the different results obtained are clearly due to the different amounts of work put on each piece. A piece from the original ingot was not tested, but would have had a tensile strength of about 45,000 or 50,000 pounds, and no elongation. The following are the results of the other tests:

| | Tensile Strength. | Reduction. | Fracture. |
|---|---|---|---|
| 16-inch forging, | 60,000 pounds | 5 per cent. | granular and brittle. |
| 8-inch forging, | 75,000 " | 14 " | less granular. |
| ⅜-inch plate, | 85,000 " | 18 " | fibrous and tough. |

THE CHEMICAL CONSTITUTION OF STEEL.—The study of the chemistry of steel makes us have a wholesome respect for the value and importance of little things. When we come to consider the fact that three or four hundredths of one per cent. of carbon

affects the tensile strength of a piece of steel, we begin to understand the value of any method by which we may obtain a rapid and accurate knowledge of the amount of this substance present. Moreover, we will understand why the results of the thousands of physical tests that have been made are still unsatisfactory. The incompleteness of these results seems to be more from the manner in which the tests have been made, rather than from any impossibility or inherent difficulty in obtaining the required information. That is, in a vast majority of cases they have been made without regard to the chemical contents of the steel. The physical test will tell us *what* qualities a certain piece of steel possesses, but it will not tell us *why* it possesses these qualities. This chemistry will do. What we require in order to have an accurate knowledge of steel is a series of alloys of iron with carbon, phosphorus, manganese, silicon, etc., alone and in combination with each other. We shall then be able to determine the influence of a unit of each of these substances on iron; our knowledge will be no longer merely empirical, and we will be able to foretell the physical properties of steel with as much accuracy as we do the properties of a substance obtained by a chemical reaction.

The influence of carbon on steel is better known than that of any other substance which enters into its composition. No one, however, so far as I am aware, has done anything more than formulate the general law that tensile strength increases with the carbon, other things being equal. I have made the interesting observation that this increase is almost exactly 1,000 pounds for every $\frac{1}{100}$th of one per cent. of carbon. That is to say, assuming $\frac{1}{100}$th of one per cent. of carbon to be a unit of carbon, then if to 45,000 pounds (the tensile strength of pure wrought iron) we add as many thousand pounds as there are units of carbon, we shall be able to make a very close approximation to the tensile strength. Boiler plate steel for example has about ·15 per cent. carbon and $15+45=60$, or about the tensile strength of boiler plate steel. Rail steel has about ·30 per cent. carbon and $30+45=75$, or about the tensile strength of rail steel. Again, crucible tool steel contains from ·50 to ·85 per cent. of carbon and these numbers added to 45, 95 and 130 respectively, include the tensile strengths of various kinds of tool steel. Still again, a sample of spring steel tested at

Altoona showed 1.00 per cent. of carbon; its tensile strength, therefore, should be 145,000 pounds. Its actual tensile strength proved to be 143,000 pounds. Of course, this law only holds good where other things are equal. An undue amount of one or all of the other foreign substances that enter into the composition of steel, or unusual physical conditions, would change the results entirely. It may be of value, however, in pointing out the fact that, when steel with a known amount of carbon does not possess a certain tensile strength, then the other substances entering into its composition are present in undue proportion or it must have been made under unusual physical conditions. The influence of manganese on steel is much more of a disputed question than that of carbon. Some metallurgists believe it to be extremely injurious, while others hold it to be very beneficial. There is no question, however, about its effect on steel so far as tensile strength is concerned, which increases as the percentage of manganese increases, although not so rapidly as with carbon. I believe, however, that when alloys of pure iron and manganese are made, it will be found that the increase of tensile strength is not due to manganese *per se*, but to its power of causing carbon to combine with the iron. In other words, it has not yet been shown; so far as I am aware, that an alloy of iron and manganese without carbon possesses unusual tensile strength. But manganese plays a dual part, it not only increases tensile strength, but, in the process of manufacture, it reacts powerfully on the oxide of iron which the steel contains and forms a fusible slag, which, being specifically lighter, rises to the top when the steel is in a molten condition, and thus renders it more homogeneous and consequently stronger and more ductile. This, however, is only true up to a certain point, beyond that point the steel gets more and more brittle until two per cent. is reached, when the steel is so brittle that a bar or rail can readily be broken by throwing it on the ground. It has recently been discovered, however, that if the percentage is increased to seven per cent., that this brittleness commences to disappear and the metal, although exceedingly hard, begins to get tough again, and when it is increased from twelve to fifteen per cent., the metal is harder than the best tool steel and almost as tough as boiler plate. I have recently seen a piece of this remarkable steel, which had a tensile strength of over 100,000 pounds to the square inch and an elonga-

tion of twenty per cent. in two inches. The alloy is the invention of Mr. Hadfield, of Sheffield, England, a well known crucible steel manufacturer. I have been unable, as yet, to formulate any definite law regarding the influence of a unit of manganese. In order to do this, a knowledge of the physical qualities of pure manganese should first be obtained, as no reliable experiments have ever been made to demonstrate these qualities. That it is a matter of the first importance, and of exceedingly great scientific interest, all must admit.

It does not seem probable that pure manganese would possess a tensile strength greater than pure iron; if it does not, must not the increased tensile strength of manganese steels be due to the combined carbon?

There is a greater difference of opinion regarding the influence of phosphorus than perhaps any other element that enters into the composition of steel. It has been considered by a majority of the best authorities that phosphorus is a hardener. The result of an immense number of tests that I have made, point in exactly the opposite direction. I have found that phosphorus in steel acts in the same manner physically as it does in pig iron, and, if I may be allowed the expression, is a "rotter," not a "hardener." But even this generalization has to be somewhat modified, for as far back as 1874, M. Euverte, of Terre-Noire, discovered that phosphorus might be introduced into steel on condition that the proportion of carbon was correspondingly diminished, and that the less carbon the steel contained, the more phosphorus might be admitted into it without depriving it of its valuable properties.

I believe, however, that this is only relatively true, and that the same metal, without any phosphorus, is possessed of superior qualities.

I have recently seen some steel test pieces made by the Clapp-Griffiths process that contained as much as 0·50 per cent. of phosphorus, an amount which only a few months ago (and even now by a large number of steel makers) would have been considered as rendering steel utterly useless, and yet this same steel possesses more valuable qualities than wrought iron and can not only be flanged and welded, but will stand being bent double cold without cracking.

The influence of silicon on steel has been but little studied, but in my opinion it has a more injurious effect than phosphorus. We

know in a general way that silicon acts in an opposite manner from manganese and prevents the carbon from combining with the iron. Phosphorus acts in a similar manner, I believe, for it is a well known fact that high phosphorus pig irons will not "chill;" that is, the carbon will not combine with the iron.

Again, we do not know whether silicon is present as silicide or as silicate of iron. Phosphorus, in the same way, might be present as phosphide or phosphate of iron, thus making important physical changes.

But silicon possesses the remarkable property of making steel solid. When ordinary low carbon steel is cast into an ingot, it is honeycombed, or full of "blow holes." Now, if we introduce into the steel 0·2 or 0·3 of one per cent. of silicon, these holes disappear, and it is possible, therefore, to make steel castings as solid as those made of iron, and with a strength from three to four times as great. At the same time, these castings are almost as ductile as wrought iron.

Sulphur and copper make steel red short, but they are usually present in such small quantities as not to give the manufacturer any serious trouble, and therefore their precise influence has not been so carefully studied as that of other impurities. Thus we see that our knowledge only being partial, we cannot as yet predict with any certainty what influence various proportions of an impurity has.

There seem to be some characteristics about steel, however, that neither chemical nor physical tests will explain--characteristics in connection with its molecular condition; and it is possible, in this connection, that the microscope will prove an important aid. At all events it is an almost virgin field, and a conscientious microscopic analysis of steel would undoubtedly yield the most interesting results.

The future of the iron and steel industry is difficult to foretell, and, although it is far from probable that it will develop in the next fifty years with such rapidity as it has in the last three decades, yet it has not by any means reached that zenith point whence future progress is impossible, and from which point the decline in its importance begins. What I desire to-night to particularly emphasize and impress upon you, is the magnificent possibilities the Bessemer process still possesses. The puddler and the

crucible process "must go." No thoughtful man can witness the operation of puddling, or the crucible process, without being impressed with the primitive nature of our methods. They must be improved, or new ones invented. Here is a splendid field for scientific and mechanical ingenuity. In conclusion, let me say that any industry in which so many millions of dollars are invested, and which gives employment to so many thousands of men, is worthy of your profoundest consideration.*

*Table of Statistics of the Iron and Steel Trade, from the Annual Report of the Secretary of the American Iron and Steel Association. Production of the world in 1883.*

| | Pig Iron. Gross Tons. | Steel. Gross Tons. | Coal. |
|---|---|---|---|
| Great Britain, | 8,490,224 | 2,158,880 | 163,737,327 |
| United States, | 4,595,510 | 1,673,534 | 96,159,719 |
| All other countries, | 7,990,837 | 2,445,227 | 138,114,795 |
| Total, | 21,076,571 | 6,277,691 | 398,011,841 |
| | $20 | $50 | $3 |
| | 420,000,000 | 310,000,000 | 1,200,000,000 |

It will be seen from the above that the United States produced twenty-two per cent. of all the pig iron, twenty-seven per cent. of all the steel, and twenty-four per cent. of all the coal produced in the world in 1883. If we value the pig iron at $20, the steel at $50, and the coal at $3 per ton, we find this output to represent the enormous sum of nearly $2,000,000,000.

*Production of Iron and Steel in the United States and Pennsylvania in 1883.*

| | United States. | Pennsylvania. |
|---|---|---|
| Pig Iron, (net tons 2,000 pounds), | 5,146,972 | 2,638,891 |
| Rolled Iron, | 2,348,874 | 1,081,163 |
| Bessemer Rails, | 1,286,554 | 819,544 |
| Open Hearth Rails, | 9,186 | |
| All Rails, | 1,360,694 | 857,818·63 per cent. |
| Crucible Steel Ingots, | 80,455 | 63,687 |
| Open Hearth Steel Ingots, | 133,679 | 72,333 |
| Bessemer Steel Ingots, | 1,654,627 | 1,044,396 |
| All Steel, | 1,874,359 | |

From the above figures we are justified in feeling a reasonable pride in the preëminent position that Pennsylvania occupies in the iron and steel industry of the United States.

* The lecturer illustrated the subject by the exhibition of numerous test specimens.

# BOOK NOTICES.

THE NATURE OF GRAVITY. By Wm. Coutie.

Mr. Coutie is a manufacturer of steam engines and machine tools, in Troy, N. Y. He has devoted much of his leisure thought to the study of natural forces, embodying the results in a brief essay, in which he endeavors "to show that the force which unites an atom of Oxygen to an atom of Hydrogen to form an atom of water, is the same force which unites the sun and planets in their orbits, and that the ultimate atoms of all matter constantly give out those actions known as light, heat, force and gravity; that these are but different manifestations of the self-same thing, and that their combined action produce all the phenomena of Nature."

The conviction of an ultimate unity of force is as old as the days of Greek philosophy. The evidences which have been furnished by the thermo-dynamic, electric, and photo-dynamic investigations, in confirmation of such unity, have led to the system of absolute measurement, and to the introduction of a series of units based upon mass, length and time, which may be used in all kinetic measurements. Mr. Coutie appears to have gone over much of the ground which is covered by such measurements, without being aware of the extent to which his views had been anticipated.

He has displayed so much acumen in his investigations that he may well be encouraged to continue them. There is great need of many additional numerical determinations in the line of his studies, and there is some probability that if he will make such determinations, he may be led to new and important discoveries; but there will be little gained by attempting to attract public attention to the mere probabilities of a correlation of forces, which is already generally believed, although it can hardly be regarded as demonstrated.

P. E. C.

THE SOARING BIRDS. A Mechanical Problem. By I. Lancaster, Chicago, Illinois.

Mr. Lancaster has published a small pamphlet under the above title, and he also published an article in the London *Engineer*, in 1883, upon the same subject. His object in writing his paper is "to point out the direction in which effort will most likely lead to practical results; as an aid to those interested in working out the problem of artificial flight." He has a confident belief "in man's ability to navigate the atmospheric spaces at will, the only thing still remaining undone being a matter of mechanical construction, requiring neither great expenditure of money, time nor skill."

The author's views are not presented in such a form as to be satisfactory, either to mathematical or non-mathematical readers. The properties of parachutes and the direct action of atmospheric currents upon broad surfaces are correctly stated; but there are some views, in regard to the reaction of the air and a consequent propulsion against the wind, which are at variance with commonly accepted notions. It is claimed, however, that the correct-

ness of those views has already been partially confirmed by experiments, and we would cordially encourage the author to continue such experiments, until he can either find in what respects he has been mistaken, or can secure such degree of success as will satisfy those who are skeptical. P. E. C.

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A CORRELATION THEORY OF COLOR PERCEPTION. By Charles A. Oliver, A. M., M. D. Reprinted from the *American Journal of the Medical Sciences*, January, 1885.

Dr. Oliver starts from the undulatory hypothesis of light and the adaptation of each sensory organ to receive its own variety of impression. He supposes visual sensation to begin in the retina, by the primary change of an external, natural force into an equivalent nerve energy. This primary form of sensation is conducted inwardly and spread upon the intra-cranial retina, in such a form as to be readily converted into an equivalent perception, by the aid of some unknown process of mentality.

The line of investigation is a novel one; the experiments are ingenious; the results are interesting. We cordially commend the paper to the notice of our readers, and we look hopefully for important confirmation of the results which it indicates, by the pathological data which the author promises to present in support of his views. P. E. C.

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THE ARCHITECT'S AND BUILDER'S POCKET-BOOK. By Frank Eugene Kidder, C. E. John Wiley & Sons, New York.

Nothing is easier at the present day than to make a pocket-book on engineering or architectural subjects: yet nothing is more difficult in this line than to form a *good* one, for considerable knowledge of the contents is necessary, and a scientific conscience also in selecting, explaining and condensing. The writer had a friend, whose method of making a pocket-book was unique. This individual had a number of them relating to railway curves, and of nearly equal size; so he tore out of each what he wanted, sent the selection to a bookbinder, and the latter issued the edition.

Every practitioner has several pocket-books, if not many, since nearly each one contains something which suits his bent of mind. Indeed, some engineers regulate their practice by them (not a good policy, yet explaining the great number in the market). The one under consideration is well written, with clear engravings, and contains much information. Quite a set of designs for roofs is given, taken from actual buildings; and if some are not exempt from criticism, they are all interesting and instructive. Those of Gothic style are for the most part selected with taste. A complete set of tables, clearly arranged, is also given for the calculation of strains in rolled iron beams.

C. A. E.

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DISTRIBUTION OF RED STARS.—M. Pechüle, of the Copenhagen Observatory, has made a spectroscopic study of the stars in the Southern hemisphere. He found a large number of red stars, increasing in frequency in proportion to the proximity of the milky way.—*Les Mondes*, October 9, 1884.


THREE NEW WASHINGTON PORTRAITS.

*Composed of 17 Originals. From Collection of Wm. S. Baker, Esq., Philada.*

These Composites, combining the conceptions of 14 artists of Washington's time, must be more nearly accurate than any single portrait ever produced.—*W. Curtis Taylor.*

# JOURNAL
OF THE
# FRANKLIN INSTITUTE
OF THE STATE OF PENNSYLVANIA,
FOR THE PROMOTION OF THE MECHANIC ARTS.

VOL. CXX. OCTOBER, 1885. NO. 4.




## ON TIDAL THEORY AND TIDAL PREDICTIONS.

By E. A. GIESELER,
Superintendent of Construction, Fourth Light-House District.

[*Continued from Volume CXIX., page 188.*]

### II. TIDAL PREDICTIONS.

For the computations described below, there were available about 1,100 high water and as many low water observations of time and height, made at the Government pier near Cape Henlopen, and about 1,500 high water and as many low water observations of time made at various points of Delaware Bay and river as far up as Bordentown.

The first question to be decided in regard to the methodical treatment of these observations, was to which lunar transit they were to be referred; that is, which lunar transit was to be considered as having generated the high water. This question is not a new one; under the name of "the age of tides" it has been discussed, for the European coast, by such authorities as Laplace,

Lubbock and Whewell. Laplace sought to determine the generating lunar transit by means of the time at which the extremes of semi-menstrual inequality—Spring and Neap tide—make their appearance. Lubbock, in addition to these, drew within the scope of his investigation the inequalities caused by lunar parallax and declination and, on the basis of very extensive series of observations, attempted to discover the best fitting lunar transit. Whewell caused simulantaneous tidal observations to be made at a great many points of the European as well as the American coast of the Atlantic Ocean, and by the aid of these constructed his "cotidal lines," with a view thus to determine the place of origin of the Atlantic tidal wave.

None of these various investigations have rendered a definite result, and up to the present we have no certainty as to which lunar transit is the generating one. In the following computations, the immediately preceding transit has been chosen, not from the writer's conviction that it is the correct one, but simply because he did not find himself in a position to improve on a choice which has been made with very general consent for our Atlantic coast. This transit has been found to agree very well with the time of appearance of the inequalities caused by lunar declination (that is, the diurnal inequalities), while the extremes of the semi-menstrual inequalities (that is, Spring and Neap tide), as referred to it, occur about one day too late, thus pointing to an earlier lunar transit as the generating one.

As a preliminary step towards the methodical treatment of the above-mentioned observations, the so-called "first reduction" of them was made according to the following schedule for high water, a similar one being employed for low water:

*Observations of High Water at Iron Pier, Cape Henlopen.*

FIRST REDUCTION.

| Observed Date & Time of High Water. | | | Date & Time of Generating Lunar Transit. | | | Lunitidal Interval. | | LUNAR. | | Solar Declination. | Observed Reading of Gauge at High Water. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Parallax. | Declination | | |
| June | h. | m. | June | h. | m. | hrs. | min. | minutes. | degrees. | degrees. | feet. |
| 2 | 5 | 45 | 1 | 21 | 29 | 8 | 16 | 60½ | +14 | +22 | 6·50 |
| 2 | 18 | 20 | 2 | 9 | 58 | 8 | 22 | 60½ | +16 | +22 | 5·75 |

It should be noted here that an effort has been made to determine the influence of the Sun's distance, which, however, failed entirely, owing probably to the limited number of observations available; no note is therefore taken in the schedule of solar distance.

From the "first reduction," an epitome was made of the lunitidal intervals of high water and of low water (the so-called "second reduction"), grouping them in both cases according to the hour of the generating transit in twelve columns, the low water always being referred to that transit which generated the preceding high water. The grouping into twenty-four hour columns was attempted, but had to be abandoned, the number of observations not being sufficient to render reliable means in so many columns. The supposition, therefore, is that the inequalities of time from the thirteenth to the twenty-fourth hour, are an exact repetition of those from the first to the twelfth hour, with this easily-understood exception, that the influences caused by solar declination will appear reversed, in the same way and for the same reasons that the influences of lunar declination appear reversed in the two lunar groups. This supposition, although probably not entirely correct, was the nearest approximation to truth to be obtained under the circumstances. In the second reduction of high water lunitidal intervals thus made, lunar parallax and solar declination were noted for each lunitidal interval, they principally influencing the time of high water, and in the second reduction of low water lunitidal intervals thus made lunar parallax, lunar declination and solar declination were noted for each lunitidal interval, they principally influencing the time of low water. The observations were grouped so as to render apparent the amount of these various heavenly influences, and the following tables show the means thus obtained in the second reduction of high water lunitidal intervals:

### *The Influence of Lunar Parallax on the Time of High Water at Cape Henlopen.*

MEANS OF SECOND REDUCTION.

*Table 1.*—The Higher Parallaxes.

| Hour of Moon's Transit. | Number of Observations. | Luni-tidal Interval | Lunar Parallax. | Solar Declination. |
|---|---|---|---|---|
| | | hrs. min. | minutes | degrees. |
| 1 | 51 | 8 18 | 59·4 | + 0½ |
| 2 | 50 | 8 08¾ | 59·2 | — 0½ |
| 3 | 45 | 8 01½ | 59·0 | 0 |
| 4 | 48 | 7 53½ | 58·8 | — 1½ |
| 5 | 47 | 7 56 | 58·3 | — 2⅓ |
| 6 | 50 | 8 01 | 58.3 | — 2 |
| 7 | 50 | 8 14 | 58·2 | — 1½ |
| 8 | 43 | 8 27 | 58·3 | — 2½ |
| 9 | 46 | 8 37½ | 58·9 | + 0½ |
| 10 | 43 | 8 35 | 59·4 | — 1 |
| 11 | 40 | 8 33½ | 59·4 | — 2⅕ |
| 12 | 47 | 8 26½ | 59·3 | + 0¾ |

*Table 2.*—The Lower Parallaxes.

| Hour of Moon's Transit | Number of Observations. | Luni-tidal Interval. | Lunar Parallax | Solar Declination. |
|---|---|---|---|---|
| | | hrs. min. | minutes. | degrees. |
| 1 | 40 | 8 25 | 54·7 | — 3 |
| 2 | 43 | 8 15½ | 54·8 | + 0¼ |
| 3 | 49 | 8 01 | 54·8 | — 0½ |
| 4 | 58 | 7 55 | 55·0 | — 1⅔ |
| 5 | 49 | 7 54¾ | 54·9 | + 0⅕ |
| 6 | 52 | 8 03 | 55·0 | — 2 |
| 7 | 49 | 8 15¼ | 54·9 | + 0⅓ |
| 8 | 41 | 8 37½ | 54·8 | — 2⅓ |
| 9 | 40 | 8 49½ | 54·8 | — 1 |
| 10 | 43 | 8 49½ | 54·8 | + 0¼ |
| 11 | 35 | 8 47⅓ | 54·7 | + 0⅓ |
| 12 | 42 | 8 39¼ | 54·8 | + 2⅝ |

### *The Influence of Solar Declination on the Time of High Water at Cape Henlopen.*

MEANS OF SECOND REDUCTION.

*Table 3.*—The Sun declines North.

| Hour of Moon's transit. | Number of Observations. | Luni-tidal Interval. | Lunar Parallax. | Solar Declination. |
|---|---|---|---|---|
| | | hrs. min. | minutes. | degrees. |
| 1 | 43 | 8 21⅓ | 57·4 | +14 |
| 2 | 48 | 8 08½ | 57·0 | +13¾ |
| 3 | 45 | 7 57¼ | 57·0 | +15¾ |
| 4 | 48 | 7 46¾ | 56·9 | +15 |
| 5 | 46 | 7 52 | 56·5 | +14½ |
| 6 | 46 | 7 54 | 56·6 | +14¾ |
| 7 | 47 | 8 07½ | 56·5 | +14½ |
| 8 | 38 | 8 29½ | 56·6 | +13⅓ |
| 9 | 40 | 8 43 | 57·2 | +15¾ |
| 10 | 43 | 8 44 | 57·0 | +14 |
| 11 | 37 | 8 39½ | 56·9 | +13⅔ |
| 12 | 50 | 8 33½ | 57·2 | +13⅔ |

*Table 4.*—The Sun declines South.

| Hour of Moon's transit. | Number of Observations. | Luni-tidal Interval. | Lunar Parallax. | Solar Declination. |
|---|---|---|---|---|
| | | hrs. min. | minutes. | degrees. |
| 1 | 48 | 8 21⅓ | 57·3 | —14⅔ |
| 2 | 45 | 8 12⅔ | 57·3 | —14½ |
| 3 | 49 | 8 04½ | 57·2 | —15 |
| 4 | 58 | 8 00 | 56·9 | —16 |
| 5 | 50 | 7 58 | 56·7 | —15 |
| 6 | 56 | 8 08½ | 56·6 | —16 |
| 7 | 52 | 8 20⅓ | 56·6 | —14⅕ |
| 8 | 46 | 8 34 | 56·5 | —15 |
| 9 | 46 | 8 43 | 56·8 | —14½ |
| 10 | 43 | 8 40⅓ | 57·3 | —15 |
| 11 | 38 | 8 41 | 57·4 | —14¾ |
| 12 | 39 | 8 31⅓ | 57·2 | —13⅔ |

In these tables, as in all following ones, the sign + prefixed to solar declination, indicates that it is *northerly*, and the sign — prefixed to solar declination, indicates that it is southerly.

It will be noticed that in Tables 1 and 2, the differences in the means of solar declination are only slight; the differences, then, appearing in the length of the lunitidal intervals of one and the same hour in the two tables, must be attributed almost entirely to the differences in lunar parallax; in a similar way, the differences in the length of the lunitidal intervals of one and the same hour in Tables 3 and 4 must be attributed to the differences in solar declination, lunar parallax being practically the same in both tables. By means of a judicious method of approximation, we arrive at the following results, in regard to the influence of the two abovementioned heavenly conditions:

*Table 5.*—Differences in Time of High Water per Minute of Lunar Parallax, as deduced from Tables 1 and 2.

| Hour of Moon's transit. | Difference. |
|---|---|
| 1 | 2 minutes. |
| 2 | 1½ " |
| 3 | 0¾ " |
| 4 | 0 " |
| 5 | 0 " |
| 6 | 0½ " |
| 7 | 1½ " |
| 8 | 3 " |
| 9 | 3 " |
| 10 | 3 " |
| 11 | 3 " |
| 12 | 2½ " |

*Table 6.*—Differences in Time of High Water for 20° Southern Solar Declination, as deduced from Tables 3 and 4.

| Hour of Moon's transit. | Difference. |
|---|---|
| 1 | +1 minute. |
| 2 | +3 " |
| 3 | +5⅓ " |
| 4 | +8 " |
| 5 | +9 " |
| 6 | +9⅔ " |
| 7 | +8⅔ " |
| 8 | +3⅓ " |
| 9 | 0 " |
| 10 | 0 " |
| 11 | 0 " |
| 12 | 0 " |

According to the rate given in Table 5, a lower parallax retards, and a higher one accelerates, the appearance of high water (see Tables 1 and 2), which is in conformity with the previous theoretical remarks on this subject.

The sign + prefixed to the differences in Table 6, means that 20° Southern solar declination belate the high water to that extent in these hours of lunar transit, as compared with the time of high water when the Sun stands in the equator; the same amount of

Northern solar declination would accelerate the arrival of high water in the same hour to the same extent. After the twelfth hour, the matter is reversed; in the fifteenth hour, for instance, 20° of Southern solar declination cause the high water to come 5⅓ minutes earlier.

Table 7 renders the means of Tables 3 and 4, and Table 8 renders these means as reduced to the mean lunar parallax of 57 minutes and the mean solar declination of 0°; that is, the equatorial position of the Sun, such reductions having been made on the basis of Tables 5 and 6.

*Table 7.*—Means of Tables 3 and 4.

| Hour of Moon's transit. | Number of Observations. | Luni-tidal Interval. | Lunar Parallax. | Solar Declination. |
|---|---|---|---|---|
| | | hrs. min. | minutes. | degrees. |
| 1 | 91 | 8 21⅓ | 57·35 | —0⅓ |
| 2 | 93 | 8 10½ | 57·15 | —0¼ |
| 3 | 94 | 8 01 | 57·10 | +0½ |
| 4 | 106 | 7 53½ | 56·90 | —0½ |
| 5 | 96 | 7 55 | 56·60 | —0¼ |
| 6 | 102 | 8 01¼ | 56·60 | —0½ |
| 7 | 99 | 8 14 | 56·55 | 0 |
| 8 | 84 | 8 31¾ | 56·55 | —0⅚ |
| 9 | 86 | 8 43 | 57·00 | —0½ |
| 10 | 86 | 8 42 | 57·15 | —0½ |
| 11 | 75 | 8 40¼ | 57·15 | —0½ |
| 12 | 89 | 8 32½ | 57·20 | 0 |

*Table 8.*—Means of Tables 3 and 4, as Corrected according to Tables 5 and 6.

| Hour of Moon's transit. | Number of Observations. | Luni-tidal Interval. | Lunar Parallax. | Solar Declination. |
|---|---|---|---|---|
| | | hrs. min. | minutes. | degrees. |
| 1 | 91 | 8 22 | 57 | 0 |
| 2 | 93 | 8 10¼ | 57 | 0 |
| 3 | 94 | 8 01 | 57 | 0 |
| 4 | 106 | 7 53¼ | 57 | 0 |
| 5 | 96 | 7 55 | 57 | 0 |
| 6 | 102 | 8 01¼ | 57 | 0 |
| 7 | 99 | 8 13¼ | 57 | 0 |
| 8 | 84 | 8 30¼ | 57 | 0 |
| 9 | 86 | 8 43 | 57 | 0 |
| 10 | 86 | 8 42½ | 57 | 0 |
| 11 | 75 | 8 40¾ | 57 | 0 |
| 12 | 89 | 8 33 | 57 | 0 |

Mean of 1,101 observations: 8 h, 19 m., which is the corrected establishment at Cape Henlopen.

According to Table 8, the mean curve of the semi-menstrual inequality of time of high water has been constructed as shown by the heavy full line in *Figs. 16* and *17*. The small circles on such line are the means as actually derived from Table 8, and it will be noticed that their simple connection renders a continuous curve, in one case only a departure of two minutes having been necessary to

secure continuity. The broken lines in the diagrams represent the influence of solar declination and of lunar parallax. *Fig. 16* has been extended over all the twenty-four hours, in order to show the reversed action of the solar declination in the last twelve hours.

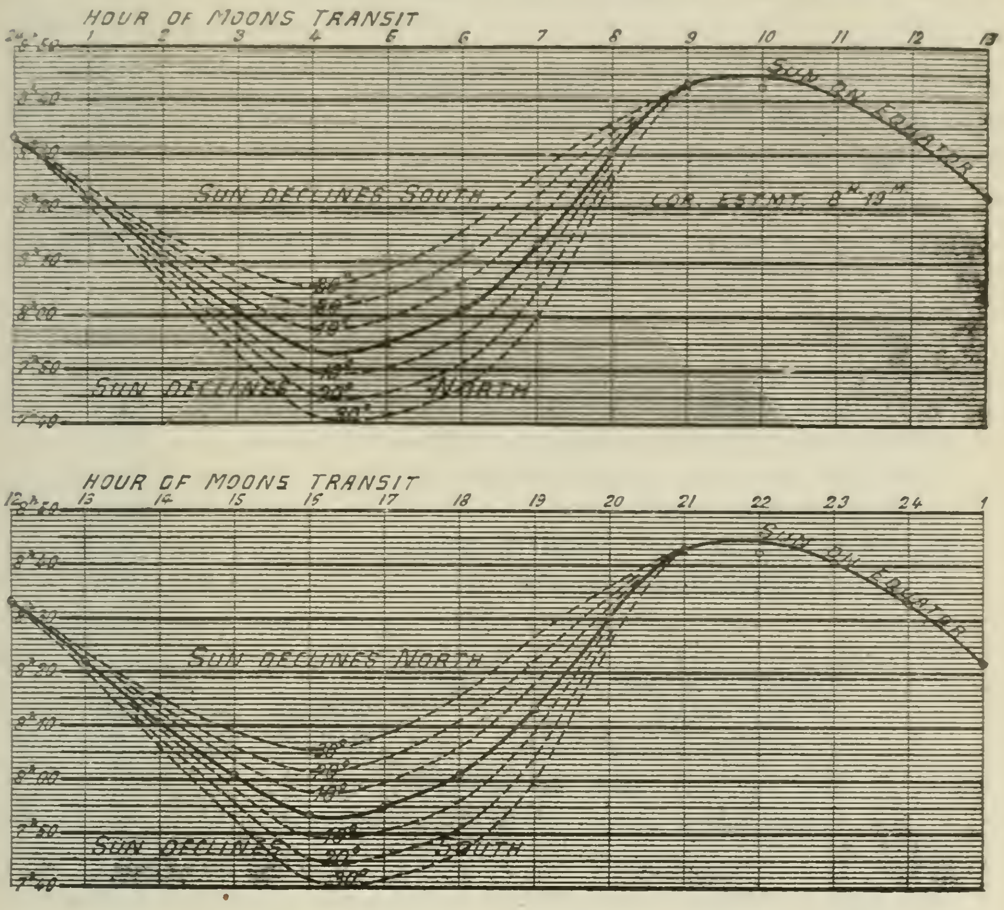


*Fig. 16.* The Curve of Semi-menstrual Inequality of the Time of High Water at Cape Henlopen, and the Influence of Solar Declination on it.

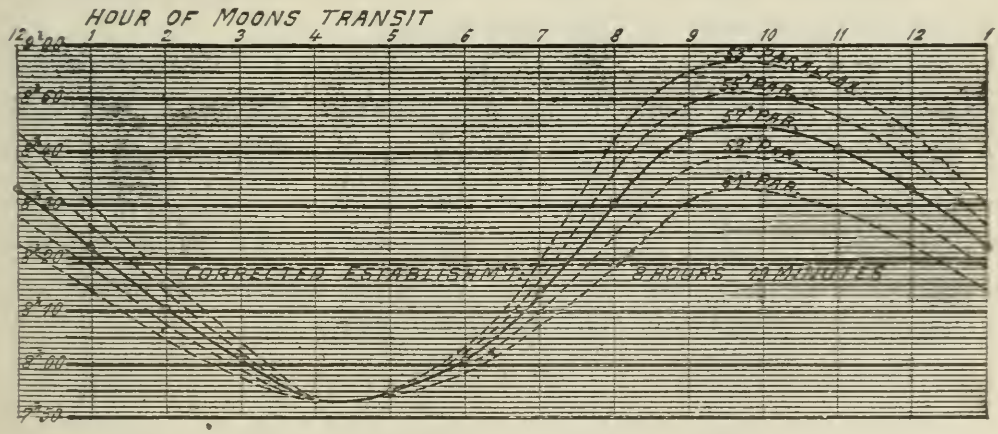


*Fig. 17.* The Curve of Semi-menstrual Inequality of the Time of High Water at Cape Henlopen, and the Influence of Lunar Parallax on it.

It should be mentioned here that the hour figures of lunar transit, as given in the diagrams, each represent the middle of such hour; thus, for instance, the figure 3 represents the middle of the third hour of lunar transit, which would be equivalent in actual time to: lunar transit at 2 h. 30 m. It is important to bear this in mind, when the curves are employed for the purpose of making predictions of the time of high water, of which the following is an example:

*Prediction of the Time of High Water at Cape Henlopen on the Morning of May 27, 1884.*

| | | Hours. | Minutes. | |
|---|---|---|---|---|
| (1.) Astronomical time of generating lunar transit, . . . . . | May 26, | 14 | 19½ | |
| (2.) Lunitidal interval, including correction for 60′ lunar parallax, as taken from *Fig. 17*, . . . | | 7 | 59 | |
| (3.) Correction for 21° Northern solar declination (from *Fig. 16*), . . | | + 0 | 05 | |
| Consequently, astronomical time of high water, . . . | May 26, | 22 | 23½ | |
| Or, civil time of high water, . . | May 27, | 10 | 23½ | A. M. |
| Time of high water as actually observed, . . . . | May 27, | 10 | 15 | A. M. |

The way in which *Figs. 16* and *17* are used to arrive at predictions is so apparent from this example, that it does not seem necessary to add any further explanation, and we now proceed to discuss the time of *low water* at Cape Henlopen.

The following tables render the means of low water lunitidal intervals, as derived from the second reduction, which was grouped in three different ways, with a view to investigate the various influences, firstly, of lunar parallax, secondly, of lunar declination, and thirdly, of solar declination. The sign — prefixed to lunar declination always indicates first lunar group, and the sign + prefixed to it always indicates second lunar group:

*The Influence of Lunar Parallax on the Time of Low Water at Cape Henlopen.*

*Table 9.*—The Higher Parallaxes.

| Hour of Moon's Transit. | Number of Observations. | Lunitidal Interval. | | Lunar Parallax. | Lunar Declination. | Solar Declination. |
|---|---|---|---|---|---|---|
| | | hrs. | min. | minutes. | degrees. | degrees. |
| 1 | 52 | 14 | 19⅓ | 59·4 | +0⅘ | +0½ |
| 2 | 52 | 14 | 08⅘ | 59·2 | +1¾ | —0½ |
| 3 | 52 | 14 | 00½ | 59·0 | +0⅘ | 0 |
| 4 | 47 | 14 | 00 | 58·8 | +1 | —1½ |
| 5 | 41 | 14 | 00 | 58·3 | —1 | —2⅓ |
| 6 | 44 | 14 | 09¼ | 58·3 | —1⅓ | —2 |
| 7 | 52 | 14 | 19 | 58·2 | —0¼ | —1½ |
| 8 | 44 | 14 | 32⅔ | 58·3 | 0 | —2½ |
| 9 | 51 | 14 | 35⅓ | 58·9 | —2⅕ | +0½ |
| 10 | 46 | 14 | 41½ | 59·4 | —1⅓ | —1 |
| 11 | 47 | 14 | 29½ | 59·4 | +0½ | —2⅕ |
| 12 | 49 | 14 | 27¼ | 59·3 | +1 | +0¾ |

*Table 10.*—The Lower Parallaxes.

| Hour of Moon's Transit. | Number of Observations. | Lunitidal Interval. | | Lunar Parallax. | Lunar Declination. | Solar Declination. |
|---|---|---|---|---|---|---|
| | | hrs. | min. | minutes. | degrees. | degrees. |
| 1 | 45 | 14 | 23 | 54·7 | —0¼ | —3 |
| 2 | 41 | 14 | 15 | 54·8 | +2¾ | +0¼ |
| 3 | 48 | 14 | 02 | 54·8 | 0 | —0½ |
| 4 | 45 | 13 | 52 | 55·0 | +0⅓ | —1⅔ |
| 5 | 46 | 14 | 00¾ | 54·9 | +1 | +0⅕ |
| 6 | 52 | 14 | 08⅗ | 55·0 | —1½ | —2 |
| 7 | 52 | 14 | 18 | 54·9 | —2⅕ | +0⅓ |
| 8 | 46 | 14 | 39½ | 54·8 | —1 | —2⅓ |
| 9 | 47 | 14 | 45¼ | 54·8 | —2¼ | —1 |
| 10 | 49 | 14 | 48 | 54·8 | —2½ | +0¼ |
| 11 | 43 | 14 | 43 | 54·7 | —2 | +0⅓ |
| 12 | 38 | 14 | 34 | 54·8 | —1¼ | +2⅚ |

*The Influence of Lunar Declination on the Time of Low Water at Cape Henlopen.*

*Table 11.*—First Lunar Group.

| Hour of Moon's Transit | Number of Observations. | Lunitidal Interval. | | Lunar Parallax. | Lunar Declination. | Solar Declination. |
|---|---|---|---|---|---|---|
| | | hrs. | min. | minutes. | degrees. | degrees. |
| 1 | 47 | 14 | 08¼ | 57·2 | —15¼ | —15 |
| 2 | 41 | 14 | 00 | 57·2 | —15½ | —12¾ |
| 3 | 47 | 13 | 50¾ | 57·0 | —15¾ | —12 |
| 4 | 47 | 13 | 42½ | 57·1 | —14 | — 8 |
| 5 | 42 | 13 | 52⅓ | 56·7 | —15¼ | — 4¾ |
| 6 | 50 | 13 | 58⅘ | 56·6 | —14¾ | — 2 |
| 7 | 58 | 14 | 09⅗ | 56·6 | —13⅙ | + 3 |
| 8 | 47 | 14 | 23½ | 56·5 | —13⅙ | + 5¾ |
| 9 | 54 | 14 | 29 | 57·0 | —13¾ | + 9½ |
| 10 | 54 | 14 | 32⅓ | 57·0 | —14 | +13¾ |
| 11 | 49 | 14 | 26 | 57·1 | —13⅙ | +13 |
| 12 | 42 | 14 | 16½ | 57·2 | —14½ | +14½ |

*Table 12.*—Second Lunar Group.

| Hour of Moon's Transit. | Number of Observations. | Lunitidal Interval. | | Lunar Parallax. | Lunar Declination. | Solar Declination. |
|---|---|---|---|---|---|---|
| | | hrs. | min. | minutes. | degrees. | degrees. |
| 1 | 50 | 14 | 31 | 57·4 | +15 | +12½ |
| 2 | 52 | 14 | 21¼ | 57·1 | +16 | +12 |
| 3 | 53 | 14 | 10⅘ | 57·2 | +14½ | + 8½ |
| 4 | 45 | 14 | 10¼ | 56·8 | +16 | + 6 |
| 5 | 45 | 14 | 08 | 56·5 | +14 | + 5½ |
| 6 | 46 | 14 | 20 | 56·5 | +13 | 0 |
| 7 | 46 | 14 | 29 | 56·6 | +14 | + 0½ |
| 8 | 43 | 14 | 50 | 56·7 | +13⅕ | — 5 |
| 9 | 44 | 14 | 53¾ | 57·3 | +12 | — 9 |
| 10 | 41 | 14 | 56½ | 57·0 | +14 | —12 |
| 11 | 41 | 14 | 48¾ | 57·4 | +14⅙ | —13½ |
| 12 | 45 | 14 | 41¾ | 57·5 | +14 | —12½ |

*The Influence of Solar Declination on the Time of Low Water at Cape Henlopen.*

*Table 13.*—Northern Solar Declination.

| Hour of Moon's Transit. | Number of Observations | Lunitidal Interval. | | Lunar Parallax. | Lunar Declination | Solar Declination |
|---|---|---|---|---|---|---|
| | | hrs. | min. | minutes. | degrees. | degrees. |
| 1 | 47 | 14 | 31¾ | 57·4 | +15 | +14 |
| 2 | 50 | 14 | 19⅗ | 57·0 | +14 | +13¾ |
| 3 | 49 | 14 | 10 | 57·0 | + 9 | +15¾ |
| 4 | 44 | 14 | 03⅖ | 56·9 | + 8 | +15 |
| 5 | 45 | 14 | 05 | 56·5 | + 3 | +14½ |
| 6 | 47 | 14 | 14⅓ | 56·6 | 0 | +14¾ |
| 7 | 56 | 14 | 18⅓ | 56·5 | — 2½ | +14½ |
| 8 | 49 | 14 | 29¾ | 56·6 | — 5 | +13½ |
| 9 | 54 | 14 | 30⅘ | 57·2 | — 9 | +15¾ |
| 10 | 59 | 14 | 34⅗ | 57·0 | —11 | +14 |
| 11 | 49 | 14 | 24½ | 56·9 | —12½ | +13½ |
| 12 | 46 | 14 | 16 | 57·2 | —13 | +13½ |

*Table 14.*—Southern Solar Declination.

| Hour of Moon's Transit. | Number of Observations. | Lunitidal Interval. | | Lunar Parallax. | Lunar Declination. | Solar Declination. |
|---|---|---|---|---|---|---|
| | | hrs. | min. | minutes. | degrees. | degrees. |
| 1 | 50 | 14 | 09 | 57·3 | —13½ | —14½ |
| 2 | 43 | 14 | 02¾ | 57·3 | —12 | —14½ |
| 3 | 51 | 13 | 53¼ | 57·2 | —10 | —15 |
| 4 | 48 | 13 | 49½ | 56·9 | — 6 | —16 |
| 5 | 42 | 13 | 55½ | 56·7 | — 3½ | —15 |
| 6 | 49 | 14 | 03⅔ | 56·6 | — 3 | —16 |
| 7 | 48 | 14 | 18⅕ | 56·6 | 0 | —14 |
| 8 | 41 | 14 | 44 | 56·5 | + 4½ | —15 |
| 9 | 44 | 14 | 51½ | 56·8 | + 6 | —14½ |
| 10 | 36 | 14 | 56 | 57·3 | +13½ | —15 |
| 11 | 41 | 14 | 49½ | 57·4 | +13½ | —14¾ |
| 12 | 41 | 14 | 44¾ | 57·2 | +15 | —13½ |

The determination of the influence of lunar parallax from Tables 9 and 10 does not present any difficulty, the other sidereal causes being practically equal in these two tables. In Tables 11 and 12, and in Tables 13 and 14, however, the influences of lunar and solar declination are blended together in most of the hours, and to obtain a result we have to resort to gradual approximation in

about the following way: A preliminary determination is made of the influence of lunar declination, using, for this purpose, only the fifth, sixth, seventh and eighth hour, during which solar declination in Table 11 is about the same as in Table 12. This preliminary determination renders three-fourths of a minute difference in time per 1° difference in lunar declination, and on the basis of this result the lunitidal intervals of Tables 13 and 14 are reduced to a lunar declination of 0°, thus to arrive at the influence of the solar declination. The values of this latter are then employed for correcting Tables 11 and 12, and thus, by gradual approximation, we finally arrive at these results:

*Table 15.*—Difference in Time of Low Water per Minute of Lunar Parallax as deduced from Tables 9 and 10.

| Hour of Moon's transit. | Difference. |
|---|---|
| 1 | 1 minute. |
| 2 | .0¾ " |
| 3 | 0½ " |
| 4 | 0 " |
| 5 | 0 " |
| 6 | 0¼ " |
| 7 | 1 " |
| 8 | 1½ " |
| 9 | 2 " |
| 10 | 2½ " |
| 11 | 2 " |
| 12 | 1½ " |

*Table 16.*—Difference in Time of Low Water for 20° Southern Solar Declination as deduced from Tables 13 and 14.

| Hour of Moon's transit. | Difference. |
|---|---|
| 1 | 0 minute. |
| 2 | —1½ " |
| 3 | —2½ " |
| 4 | —3½ " |
| 5 | —3½ " |
| 6 | —2½ " |
| 7 | 0 " |
| 8 | +5 " |
| 9 | +7 " |
| 10 | +6 " |
| 11 | +3½ " |
| 12 | +1½ " |

As to whether the figures in these tables indicate retardations or accelerations of the arrival of low water, the remarks that were made in this connection at the foot of Tables 5 and 6 also apply here.

For the influence of lunar declination, we obtain from the corrected figures of Tables 11 and 12 the result that 10° difference in declination will cause a difference of about $7\frac{1}{10}$ minutes in time, the question of retardation or acceleration here depending, as we know, on the lunar group.

Table 17 renders the means of Tables 11 and 12, and Table 18 renders these means as reduced to the mean lunar parallax of 57

minutes, and the mean lunar and solar declination of 0°; that is, the equatorial position of Sun and Moon, such reduction having been made on the basis of Tables 15 and 16 and the above given magnitude of influence of lunar declination.

*Table 17.*—Means of Tables 11 and 12.

| Hour of Moon's transit. | Number of Observations. | Lunitidal Interval. | | Lunar Parallax. | Lunar Declination. | Solar Declination. |
|---|---|---|---|---|---|---|
| | | hrs. | min. | minutes. | degrees. | degrees. |
| 1 | 97 | 14 | 19½ | 57·30 | 0 | —1¼ |
| 2 | 93 | 14 | 10½ | 57·15 | +0¼ | —0½ |
| 3 | 100 | 14 | 00¾ | 57·10 | —0½ | —1¾ |
| 4 | 92 | 13 | 56½ | 56·95 | +1 | —1 |
| 5 | 87 | 14 | 00 | 56·60 | —0½ | +0½ |
| 6 | 96 | 14 | 09½ | 56·55 | —1 | —1 |
| 7 | 104 | 14 | 19¼ | 56·60 | +0½ | +1¾ |
| 8 | 90 | 14 | 36¾ | 56·60 | 0 | +0½ |
| 9 | 98 | 14 | 41½ | 57·15 | —1 | +0¼ |
| 10 | 95 | 14 | 44½ | 57·00 | 0 | +1 |
| 11 | 90 | 14 | 37½ | 57·25 | +0½ | —0¼ |
| 12 | 87 | 14 | 29 | 57·35 | —0¼ | +1 |

*Table 18.*—Corrected Means of Tables 11 and 12.

| Hour of Moon's transit. | Number of Observations. | Lunitidal Interval. | | Lunar Parallax. | Lunar Declination. | Solar Declination. |
|---|---|---|---|---|---|---|
| | | hrs. | min. | minutes. | degrees. | degrees. |
| 1 | 97 | 14 | 20 | 57·0 | 0 | 0 |
| 2 | 93 | 14 | 10½ | 57·0 | 0 | 0 |
| 3 | 100 | 14 | 01½ | 57·0 | 0 | 0 |
| 4 | 92 | 13 | 55¾ | 57·0 | 0 | 0 |
| 5 | 87 | 14 | 00½ | 57·0 | 0 | 0 |
| 6 | 96 | 14 | 10¼ | 57·0 | 0 | 0 |
| 7 | 104 | 14 | 18¼ | 57·0 | 0 | 0 |
| 8 | 90 | 14 | 36 | 57·0 | 0 | 0 |
| 9 | 98 | 14 | 42½ | 57·0 | 0 | 0 |
| 10 | 95 | 14 | 44¾ | 57·0 | 0 | 0 |
| 11 | 90 | 14 | 37½ | 57·0 | 0 | 0 |
| 12 | 87 | 14 | 29¾ | 57·0 | 0 | 0 |

Mean of 1,129 observations: 14 h. 20½ m., which is mean low water lunitidal interval at Cape Henlopen.

According to Table 18, the mean curve of the semi-menstrual inequality of the time of low water has been constructed as shown by the heavy full line in *Figs. 18* and *19*. The small circles on such line are the means as actually derived from Table 18, and it will be noticed in this case also, that the continuity of the curve necessitated only very trifling departures from the means as actually found. The broken lines in the diagrams represent the influence of lunar parallax and declination. The influence of the solar declination (Table 16) has not been represented, the results found for it not being considered very reliable, on account of the heavy corrections and following therefrom the indirectness of the way required to obtain them.

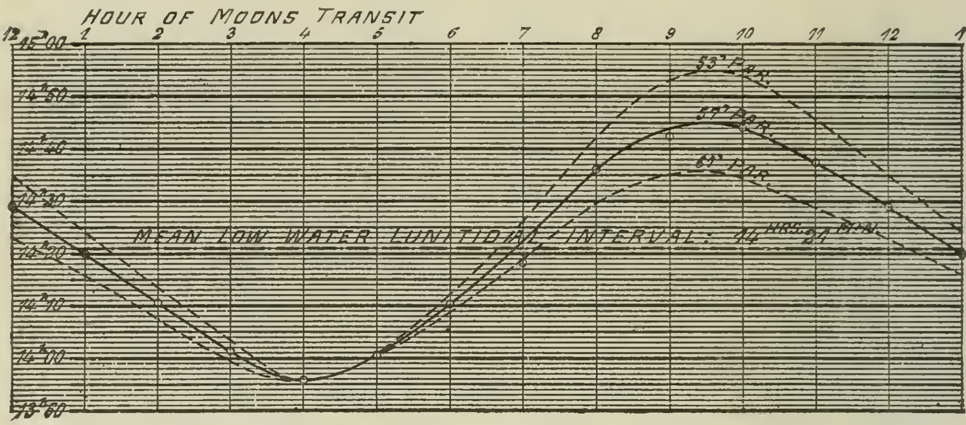


*Fig. 18.* The Curve of Semi-menstrual Inequality of the Time of Low Water at Cape Henlopen, and the Influence of Lunar Parallax on it.

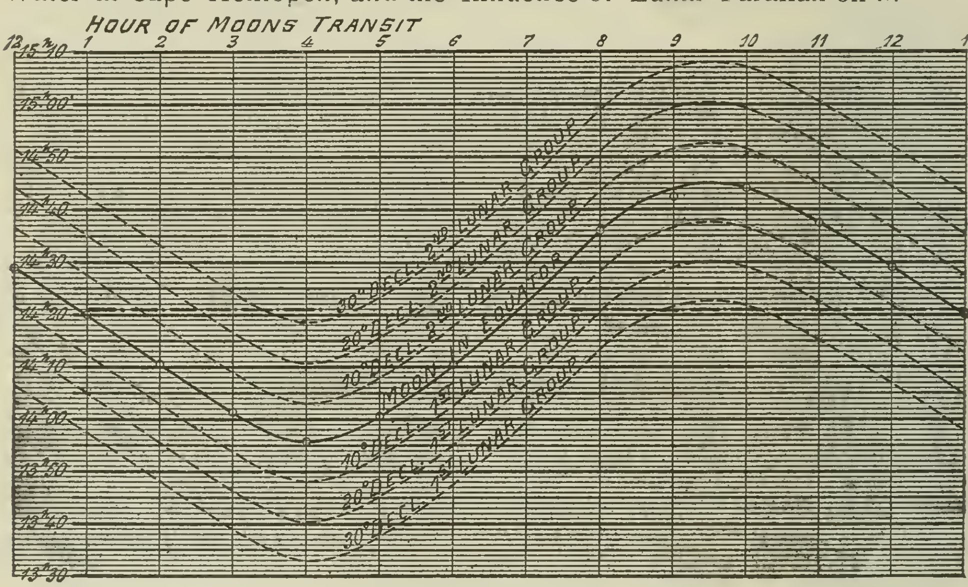


*Fig. 19.* The Curve of Semi-menstrual Inequality of the Time of Low Water at Cape Henlopen, and the Influence of Lunar Declination on it.

The following is an example of utilizing the curves of *Figs. 18* and *19* for the purpose of predicting the time of low water.

*Prediction of the Time of Low Water at Cape Henlopen on the Afternoon of May 27, 1884.*

| | | Hours. | Minutes. | |
|---|---|---|---|---|
| (1.) Astronomical time of generating lunar transit, . . . . . . | May 26, | 14 | 19½ | |
| (2.) Lunitidal interval, including correction for 60′ lunar parallax, as taken from *Fig. 18*, . . . . . | | 14 | 01½ | |
| (3.) Correction for 18° lunar declination, first group (from *Fig. 19*), . . | | — 0 | 13 | |
| Consequently, astronomical time of low water, . . . . | May 27, | 4 | 08 | |
| Or, civil time of low water, . . | May 27, | 4 | 08 | P. M. |
| Time of low water as actually observed, . . . . | May 27, | 4 | 10 | P. M. |

Deducting the above found corrected establishment from the mean low water lunitidal interval, we find the mean duration of fall, and deducting this from the mean duration of half a lunar day, we obtain the mean duration of rise. These operations render

| | Hours. | Minutes |
|---|---|---|
| Mean low water lunitidal interval at Cape Henlopen, . | 14 | 20½ |
| Corrected establishment at Cape Henlopen, . . . . | 8 | 19 |
| Consequently mean duration of fall, . . . . . | 6 | 01½ |
| And mean duration of rise, . . . . . . . | 6 | 23½ |

We now proceed to discuss the time of the event of high and of low water at various points along the Delaware and the Pennsylvania shore, above Cape Henlopen as far up as Bordentown.

The first efforts of the writer in this direction were made several years ago in this way, that all the simultaneous observations available at the various points were compared, and the time of propagation of high and of low water from one point to the other derived, all such times being finally referred to Cape Henlopen as the starting point. The results obtained in this way are embodied in a table, which has been published by Professor Henry Mitchell, on page 8 of Appendix, No. 18, to the Coast Survey Report of 1881.

The present results have been arrived at by first determining "corrected establishment" and "mean low water lunitidal interval" for the following points independently of each other, in the same way as determined above for Cape Henlopen:

| | |
|---|---|
| Edgemoor, | Fort Mifflin, |
| Marcus Hook, | Five Mile Point. |

Together with Cape Henlopen, five standard points were thus obtained, and each of the intermediate points was then referred to two or more of such standard points, with the exception of Collins Beach, where simultaneous observations, with only one standard point, were available. In this way a check on the correctness of the computations was obtained, which the above-mentioned earlier results do not possess. If, in addition to this, it is remembered that the number of observations employed at present aggregates about five times as many as the number available for the earlier work, then the writer may appear justified in claiming his present results to be not far from the truth, and certainly nearer to it than his earlier ones.

The following table renders the results obtained and also shows from how many observations each of them was found, thus giving a fair scale for the reliability of each result.

*Table 19.*—The Time of High and of Low Water at various Points on Delaware Bay and River.

| No. | Name of Station. | Distances in Nautical Miles from Cape Henlopen. | Corrected Establishment. | Number of Observations. | Mean Low Water Luni-Interval. | Number of Observations. | Time of Propagation from Cape Henlopen. of High Water. | Time of Propagation from Cape Henlopen. of Low Water. | Duration of Rise. | Duration of Fall. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | hrs. min. | | hrs. min. | | hrs. min. | hrs min. | hrs. min. | hrs. min. |
| 1 | Cape Henlopen, . . | 0 | 8 19 | 1101 | 14 20½ | 1129 | 0 | 0 | 6 23½ | 6 01½ |
| 2 | Collins Beach, | 42·1 | 10 21½ | 21 | 17 09 | 20 | 2 02½ | 2 48½ | 5 37½ | 6 47½ |
| 3 | Port Penn, . | 49·4 | 10 52½ | 75 | 17 50 | 67 | 2 33½ | 3 29½ | 5 27½ | 6 57½ |
| 4 | Ft. Delaware, | 54·2 | 11 14 | 45 | 18 08½ | 38 | 2 55 | 3 48 | 5 20½ | 7 04½ |
| 5 | New Castle, . | 58·9 | 11 34 | 80 | 18 45 | 80 | 3 15 | 4 24½ | 5 14 | 7 11 |
| 6 | Pigeon Point, | 61·9 | 11 41½ | 59 | 18 56 | 64 | 3 22½ | 4 35½ | 5 10½ | 7 14½ |
| 7 | Edgemoor, . | 64·7 | 11 56½ | 384 | 19 16½ | 426 | 3 37½ | 4 56 | 5 05 | 7 20 |
| 8 | Marcus Hook, | 70·4 | 12 14½ | 362 | 19 40 | 339 | 3 55½ | 5 19½ | 4 59½ | 7 25½ |
| 9 | Fort Mifflin, . | 80·9 | 13 09¾ | 395 | 20 37½ | 400 | 4 50¾ | 6 17 | 4 57¼ | 7 27¾ |
| 10 | Five Mile Pt. | 92·1 | 14 12½ | 179 | 21 41½ | 161 | 5 53½ | 7 21 | 4 56 | 7 29 |
| 11 | Bordentown, | 112·4 | 16 19 | 44 | 23 44 | 56 | 8 00 | 9 23½ | 5 00 | 7 25 |

The results for Bordentown are apparently the least satisfactory ones. Instead of the duration of fall further increasing, as in reality

it most likely does, our table shows a slight decrease as compared with Five Mile Point. The reason probably is to be sought in the fact, that all observations available for Bordentown were made during the dry season of the year, when the fresh water flow from above was comparatively small. Future observations, extending through all seasons of the year, will in all likelihood render a longer low water lunitidal interval and consequently a longer duration of fall at this point.

If the times of propagation from Cape Henlopen, as given in Table 19, are laid off as ordinates, the distances from Cape Henlopen being the abscisses, then two lines are obtained (one for high and one for low water), which, although irregular, yet approach regularity to such a degree, that one might be tempted, by means of some alterations, to substitute continuous curves for them. But in the first place the alterations necessary for this, at such points as Marcus Hook and Fort Mifflin, would, in the writer's opinion, exceed the limit of possible error in the lunitidal intervals as determined above for these points, which limit he does not place any higher than two or three minutes. Again, there is no reason to believe that the line in question should be a continuous curve, but there is on the contrary much reason to believe that it cannot be one, as the following deduction may serve to show.

The below-named conditions may be said to determine the resistances which the tidal wave in its course upwards has to overcome, and consequently likewise to determine the velocity of its propagation:

(1.) Grade of river bottom.

(2.) Form and size of cross-sectional areas.

(3.) Curvature of river.

(4.) Fresh water flow.

(5.) Rise and fall of tide at mouth.

(6.) Distance of propagation.

The two last-named conditions are practically constants, and if for the four others we assume as follows:

(1.) Uniform grade throughout;

(2.) Uniform shape of cross-sections, and decrease of cross-sectional areas according to a continuous law;

(3.) Uniform curvature throughout;

(4.) Uniform fresh water flow throughout, coming down in the river bed only, no tributaries existing;

then the supposition would be justified that the velocity of propagation of high and low water would decrease, according to a continuous law, and that hence our above-described graphical representations of such velocity would assume the form of continuous curves.

None of the above-made suppositions, however, exist in reality. The tidal wave, therefore, in its course upwards, has to overcome resistances of a continually fluctuating character, each of them individually now increasing, now decreasing, and it would be a most remarkable and not-to-be-looked-for result if, under these circumstances, the fluctuations of the various resistances were at all places so to balance each other as to cause a decrease of velocity subject to a law expressible in a continuous curve. In the writer's opinion, therefore, the velocity of the tidal wave moving up any river is a quantity decreasing on the whole, but subject to local irregularities corresponding to the local conditions of the river bed. It seems quite possible that researches extended over a number of rivers may reveal the amount of influence exercised by each of the above-named conditions, and that thus we may be enabled, from a full knowledge of such conditions in any given case, to draw conclusions in regard to the propagation of the tidal wave.

Table 19 can be utilized for predicting the time of high and low water at any of the points contained in it in this way, that the prediction is first made for Cape Henlopen, as described before, and that then the time of propagation for the point in question, as taken from the table, is added. This time of propagation is, however, by no means a constant, but is influenced by the hour of lunar transit, by lunar declination, and by lunar parallax; and the attempt has been made, from the joint observations for Edgemoor, Marcus Hook and Fort Mifflin, to determine the magnitude of such influences for the region of these points.

The influence of lunar parallax, although apparent, could not be determined with any accuracy.

The influence of lunar declination on the time of propagation of low water was found to amount to about two minutes per 5° of declination, the correction to be applied in the sense of the two lunar groups.

The influence of the hour of Moon's transit is apparent from the following two curves of semi-menstrual inequality.

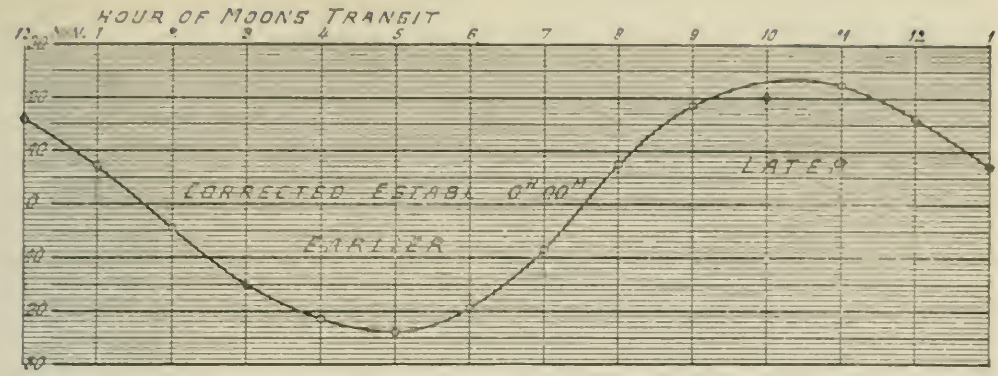


*Fig. 20.*—The Curve of Semi-menstrual Inequality of the Time of High Water in the Region of Edgemoor, Marcus Hook and Fort Mifflin, as deduced from 1,141 Observations.

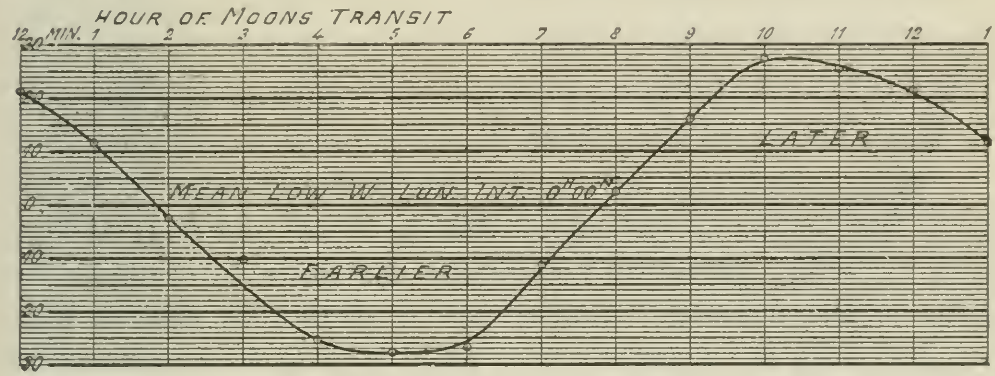


*Fig. 21.*—The Curve of Semi-menstrual Inequality of the Time of Low Water in the Region of Edgemoor, Marcus Hook and Fort Mifflin, as deduced from 1,165 Observations.

As indicated by the headings, these curves were obtained by averaging the means for each lunar hour of the above-named three points, thus rendering a result for some point (within the region named), the exact position of which is not known, and for which was found: Corrected establishment = 12 hours, 26⅔ minutes, and mean low water lunitidal interval = 19 hours, 51 minutes. The shape of the curves cannot, in the entire region, vary very much, and they may, consequently, with safety, be applied to any of the three points by simply substituting his corrected establishment in the case of high water, and his mean low water lunitidal interval in the case of low water.

From a comparison of these two curves with the ones found for Cape Henlopen, we deduce the following tables of corrections, to be applied to the times of propagation of high and low water (as taken from Table 19) in each hour of lunar transit.

*Table 20.*—Corrections for Time of High Water.

| Hour of Moon's Transit. | Correction in Minutes. |
|---|---|
| 1 | +4 |
| 2 | +4 |
| 3 | +3 |
| 4 | +4 |
| 5 | 0 |
| 6 | —2 |
| 7 | —3 |
| 8 | —4 |
| 9 | —5½ |
| 10 | —2 |
| 11 | +0½ |
| 12 | +2 |

*Table 21.*—Corrections for Time of Low Water.

| Hour of Moon's Transit. | Correction in Minutes. |
|---|---|
| 1 | +13 |
| 2 | + 8½ |
| 3 | + 5½ |
| 4 | 0 |
| 5 | — 8½ |
| 6 | —15¼ |
| 7 | —13 |
| 8 | —12 |
| 9 | — 6½ |
| 10 | + 3¾ |
| 11 | +11½ |
| 12 | +12¾ |

These corrections will apply approximately also to points above the region of Edgemoor, Marcus Hook and Fort Mifflin, while for points below the corrections can easily be obtained by means of interpolation. In order now to predict the time of high and low water for a point above Cape Henlopen, we proceed as shown in the following example:

*Prediction of Time of High and Low Water at Marcus Hook, on May 27, 1884.*

| | Hours. | Minutes. |
|---|---|---|
| (1.) Time of high water at Cape Henlopen as found before, . . . . . . . . . . | 10 | 23½ A. M. |
| (2.) Time of propagation (Table 19), . . . . | 3 | 55½ |
| (3.) Correction for third lunar hour, (Table 20) . | + | 3 |
| Consequently time of high water at Marcus Hook, . . . . . . | 2 | 22 P. M. |
| (1.) Time of low water at Cape Henlopen as found before, . . . . . . . . . . | 4 | 10 P. M. |
| (2.) Time of propagation (Table 19), . . . . | 5 | 19½ |
| (3.) Correction for 18° lunar declination, 1st group, | — | 7 |
| (4.) Correction for third lunar hour, (Table 21) . | + | 5½ |
| Consequently, time of low water at Marcus Hook, . . . . . . . . | 9 | 28 P. M. |

(*To be concluded.*)

# AN ACCOUNT OF THE EXPERIMENTS MADE ON A CONDENSING COMPOUND ENGINE, BY A COMMITTEE OF THE INDUSTRIAL SOCIETY OF MULHOUSE, IN ALSACE, GERMANY.

BY CHIEF ENGINEER ISHERWOOD, U. S. N.

In 1878, a medal of honor was offered by the Industrial Society of Mulhouse, in Alsace, Germany, for the first compound engine constructed in upper Alsace, that would give the French horse-power (32544·17077 pounds raised one foot high per minute), *as shown by a friction brake* for not more than the weight of nine kilograms (19·8416 pounds) of steam consumed per hour, equivalent to about 17·44 pounds of steam consumed per hour *per indicated English horse-power.*

In 1879, the above challenge was accepted by Messieurs C. Weyher and Richemond, agents of the Central Company for the construction of the Pantin engine, who offered for the prize one of their engines then in operation at the spinning factory of Mr. Antoine Herzog, at Colmar, Alsace, and which had been regularly working about fourteen months.

Accordingly, the Industrial Society directed its Committee on Mechanics, consisting of Messieurs Goerich, Grosseteste, X. Fluhr, Keller, Poupardin and Walter Meunier, to experiment with and report upon the engine offered. These gentlemen made several very careful tests, and most accurately ascertained the cost in pounds of feed water consumed per hour of the indicated horses-power developed in the cylinders, and of the horses-power delivered to the shafting of the factory as determined by a friction brake applied to the engine shaft; but they did not make the most of their opportunity and labor, by ascertaining the condensation of steam in the cylinders and other interesting facts, although the data in their possession would have enabled them to do so with very little additional work. They do not even state the measure of expansion with which the steam was used, nor at what point of the stroke of the pistons the steam was released from and cushioned in the cylinders, though these facts are essential to an

understanding of the causes producing the particular results obtained. They do, indeed, give a specimen indicator diagram from each end of the two cylinders for each experiment, from which the reader may ascertain approximately when the steam was cut off, released and cushioned, but they should have given the mean fraction of the stroke of the pistons from all the diagrams, at which these operations upon the steam took place. The back pressures against all the pistons should also have been given, both including and excluding the cushioning, and the back pressure against each piston at the point where the cushioning commenced should have been given. Likewise, the mean pressure of the expanded steam alone should have been given, and the pressure at the end of the stroke of each piston. The omissions mentioned could have readily been supplied from the diagrams in possession of the committee, and always should be in every case of experimenting with steam engines, as without this information only a very imperfect idea can be had of the more or less proper distribution of the pressures in the cylinders, and to what degree the economy of the steam may have thus been affected; a proper experiment and report ascertains and presents the *whole* subject, nothing is more unsatisfactory than partial data which may easily lead to erroneous conclusions. Had a drawing been given of the boiler, and had the coal been weighed that was consumed during the long experiments of October 22d and 23d, each of over twelve hours' duration, the data of a boiler experiment would have been completed, for all the other quantities are given, and the value of the investigation that much extended. It is true that the coal was weighed during the experiments of July 7th and 8th, but they were entirely too short for reliable vaporizations, being only from three to four hours long.

The report of the committee will be found in the *Bulletin of the Society*, for January and February, 1880, pages 5 to 20, in which are detailed the methods of observation and calculation employed, and the results obtained.

From this report, the following facts have been taken as far as given, and the remainder supplemented from the indicator diagrams above mentioned. No regard has been had to the arrangement, calculations, or inferences of the committee; their observed facts alone have been used.

The feed water was carefully measured in a tank before being pumped into the boiler. It was a portion of the water delivered from the jet condenser by the air-pumps.

The condensing water was also carefully measured in a tank before it entered the jet condenser; and the quantity of combined condensing water and water of steam condensation withdrawn from the condenser by the air-pumps, was likewise measured in another tank into which it was thrown by these pumps.

Indicator diagrams were taken every twenty minutes from each end of each cylinder, and from the mean pressure shown by all of them, the indicated horses-power were computed.

By a very excellent arrangement of friction brake applied to a drum on the engine-shaft, there were ascertained the number of horses-power delivered by the engine to the factory shafting. Of course, this power was less than the indicated power by the friction resistance of the engine *per se*, or unloaded, and by the friction of the load on the journals and guides of the working parts of the engine.

The entire work of the engine during the experiments of July 7 and 8, 1879, consisted in overcoming the friction produced by the brake. During each of these experiments, the steam pressure in the boiler was maintained almost without variation, the point at which the steam was cut off in the cylinders remained fixed, and the throttle valve was kept wide open, so that the mean of all the indicator diagrams taken must represent, with absolute accuracy, the mean performance of the engine.

The number of double strokes made by the pistons of the engine was taken from a counter; and, in the weighing and measuring of the several observed quantities, all the usual corrections were made. The indicators were also carefully measured and tested.

A sufficient number of qualified assistants were employed to secure absolute accuracy in the quantities observed.

The data and result of these experiments, made in July, 1879, will be found in the following, Table No. 1. In the succeeding October, the committee made two additional trials on the engine while doing its regular work at the factory, each of which continued a little over twelve hours, in order to test the accuracy of the July experiments, and to ascertain whether the engine when functioning under the conditions of ordinary practice gave the same

economic returns as when tried under the previous experimental conditions. The results of the October tests will be found in the following Table No. 2, which contains all the data taken.

Before proceeding to an examination of the tables, it is necessary to have the description and dimensions of the engine, given below:

ENGINE.

The engine is of the portable kind; that is, it is secured upon the top of its boiler, the latter being cylindrical and horizontal, with lugs attached by which it can be placed temporarily on any foundation and readily removed from place to place.

The engine works with condensation, and consists of two compounded cylinders of unequal diameters and equal strokes of pistons, lying horizontally side by side and bolted to a strong cast iron bed-plate, which in turn is bolted to the top of the boiler. The cylinders are direct acting, with piston rods secured into cross-heads working between guides, from which crossheads connecting rods extend to the crank-pins of the shaft. The shaft is horizontal and curved out into cranks opposite the respective cylinders. It is supported by three pillar-blocks, one at each end outside the cranks, and the third midway between the two. One of the projecting ends of the shaft carries the fly-wheel. The eccentrics for operating the valves of both cylinders are keyed at proper positions upon the shaft. The valve chest of each cylinder is upon its outer side.

The steam valve of the small cylinder is the usual short slide operated by the usual eccentric. In addition to the steam valve, there is an independent slide cut-off valve operated by an eccentric, and capable, through suitable mechanism, of varying the point at which the steam is cut off by means of the usual governor acting upon a double cam. When the engine is in operation, the point of cutting off automatically varies with variations of the load.

The large cylinder has no independent cut-off valve; its steam valve is the usual short slide operated by the usual eccentric. The steam is cut off, however, at an invariable point in the large cylinder, by means of lap on the steam side of the steam valve. The valves of neither cylinder were counterbalanced, but worked with the full valve chest pressure upon their backs.

As the load of the engine during the experiments of July 7th and 8th, hereinafter described, consisted entirely of friction produced by a brake carrying the weight always at the same leverage, which weight was the same for all the experiments except that of the morning of July 8th, in which it was reduced nearly one-half, the point of cutting off in the small cylinder remained invariable throughout each experiment. For the experiment of the morning of July 8th, the steam was cut off in the small cylinder at 0·25 of its stroke from the commencement, and for the remaining experiments at 0 42 of its stroke. The steam in all the experiments was released from the small cylinder when 0·98 of the stroke of its piston was completed, and cushioned when 0·925 of the return stroke was completed.

The point of cutting in the large cylinder, during the abovementioned experiments, was when 0·45 of the stroke of the piston was completed. The steam was invariably released from the large cylinder when 0·91 of the stroke of its piston was completed, and cushioned when 0·75 of the return stroke was completed.

The small cylinder has a steam jacket covering its entire cylindrical surface, the jacket being interposed between the cylinder and the valve chest. By this arrangement, the bottom of the valve chest becomes steam jacketed, which is advantageous to the economy, but the steam passages are lengthened by the width of the jacket, which is disadvantageous to a much greater degree. The ends of the cylinder are not jacketed.

The exhaust steam from the small cylinder contours the upper part of the outside of the jacket of that cylinder, taking heat from the jacket, and is delivered to the steam valve of the large cylinder after traversing a passage or jacket contouring the upper part of the large cylinder to its valve chest. The lower part of the large cylinder, excepting the surface covered by its valve chest, has a steam jacket which receives its steam directly from the boiler. Only one-half of the cylindrical surface of the large cylinder is jacketed with steam taken immediately from the boiler. The remainder of this surface is covered by the valve chest and by the exhaust passage leading to it from the small cylinder. The valve chest of the large cylinder is cast upon the cylinder itself, the side of which forms the bottom of the chest, so that no jacket space interposes between them as in the case of the small cylinder. Neither end of the large cylinder is jacketed.

There is no separate steam pipe leading from the boiler to the jackets of the cylinders. The main steam pipe delivers the boiler steam into the jacket of the small cylinder a little above the lowest point of that jacket. This pipe has an inclination downwards to the boiler, made in the expectation that the water of condensation from the jackets would drain back by gravity to the boiler. From the jacket, the steam enters the small cylinder.

The steam jacket of the large cylinder receiving its steam directly from the boiler, is supplied through a short branch from the main steam pipe, which branch enters that jacket a little above its lowest point.

To resume: Both the heads of both cylinders are not steam jacketed. The entire cylindrical surface of the small cylinder and one-half of this surface of the large cylinder are steam jacketed. The remaining half of the cylindrical surface of the large cylinder is covered by its valve chest and by the exhaust passage leading to it from the small cylinder.

The exterior surfaces of the cylinders, with the exception of the heads, are clad with non-heat-conducting substances.

There are two air-pumps worked by a T lever actuated by a short connecting rod articulated to the crosshead. These pumps are vertical and immersed in a tank. The feed-pump is articulated to one of the arms of the lever working the air-pumps.

There is one jet condenser of very great capacity relatively to the volume of the large cylinder. The injection water is sprayed into it by a conical rose.

The speed of the engine is automatically regulated by a Porter governor acting on the cut-off cam by means of the Denis compensator, an apparatus that Messieurs Weyher and Richemond apply to nearly all their engines with excellent results.

The following are the dimensions of the engine:

| | | |
|---|---|---|
| Diameter of the small cylinder, . . . | 11·2010 | inches. |
| Diameter of the piston rod of the small cylinder, . . . . . . . . . . . | 2·1654 | inches. |
| Stroke of the piston of the small cylinder, | 18·8980 | inches. |
| Net area of the small cylinder piston, . | 96·696816 | square inches. |
| Space displacement of the small cylinder piston, per stroke, . . . . . | 1·0575095 | cubic feet. |
| Space in clearance and steam passage at one end of small cylinder, . . | 0·0676805 | cubic foot. |

| | | |
|---|---|---|
| Per centum which the space in clearance and steam passage at one end of the small cylinder is of the space displacement of its piston, per stroke, | 6·40 | |
| Length of the steam port of the small cylinder, . . . . . . . . . . . | 4·7245 | inches. |
| Breadth of the steam port of the small cylinder, . . . . . . . . . . . | 0·9843 | inches. |
| Area of the steam port of the small cylinder, . . . . . . . . . . . | 4·6503 | square inches. |
| Diameter of the steam pipe, . . . . | 3·1497 | inches. |
| Depth of the piston of the small cylinder, | 4·7245 | inches. |
| Diameter of the large cylinder, . . . | 18·9059 | inches. |
| Diameter of the piston rod of the large cylinder, . . . . . . . . . . . | 2·1654 | inches. |
| Stroke of the piston of the large cylinder, | 18·8980 | inches. |
| Net area of the large cylinder piston, . | 278·886568 | square inches. |
| Space displacement of the large cylinder piston, per stroke, . . . . . . . | 3·0499990 | cubic feet. |
| Space in clearance and steam passage at one end of large cylinder, . . . . | 0·1525010 | cubic foot. |
| Per centum which the space in clearance and steam passage at one end of the large cylinder is of the space displacement of its piston, per stroke, | 5·00 | |
| Length of steam port of large cylinder, | 9·4490 | inches. |
| Breadth of steam port of large cylinder, | 0·9843 | inch. |
| Area of steam port of large cylinder, | 9·3006 | square inches. |
| Diameter of the exhaust pipe, . . . . | 4·5000 | inches. |
| Depth of the piston of the large cylinder, | 4·7245 | inches. |
| Distance between the axes of the two cylinders, . . . . . . . . . . | 23·6225 | inches. |
| Thickness of metal of the 2 cylinders, | 0·9843 | inch. |
| Area of the piston of the large cylinder relatively to the area of the piston of the small cylinder taken as unity, | 2·884134 | |
| Aggregate space displacement of the piston of the large cylinder per stroke, and space in clearance and steam passage at one end of that cylinder, relatively to the aggregate space displacement of the piston of the small cylinder per stroke, and space in clearance and steam passage at one end of that cylinder taken as unity, . . . . . . . . | 2·846186 | |

Table No. 1 contains all the observed quantities, and the calculated results from them, obtained during the special July trials of the engine. These quantities and results are arranged in groups for facility of reference. Each quantity and each result is so fully described on the line bearing it, that only in a few cases is any further explanation necessary.

The experiments were four in number, and were made with nearly the same piston speed in all, the difference being too small to exercise any practical effect on the economic result The boiler pressure and the condenser pressure also varied but very little during the different experiments, and the throttle valve was kept wide open in all, so that as regards these important conditions, all the experiments had equality, being made with equal boiler pressure, equal piston speed, equal throttle valve opening, and equal condenser pressure.

During all the experiments, except that of the morning of July 8th, the distribution of the steam was exactly the same, being cut off in the small cylinder when 0·42 of the stroke of its piston was completed, and in the large cylinder when 0·45 of the stroke of its piston was completed, the measure of expansion with which the steam was used being, by volume, 6·2569 times in all three experiments. For the small cylinder, the steam was released when 0 98 of the stroke of its piston was completed, and for the large cylinder when 0·91 of the stroke of its piston was completed. In the small cylinder, the cushioning of the back pressure steam commenced when 0·925 of the return or exhaust stroke of the piston was completed, and in the large cylinder when 0·75 of that stroke of its piston was completed. The three experiments, therefore, of the morning and afternoon of July 7th, and the afternoon of July 8th, were repetitional in order to secure certainty of the result on which the award of the prize was to depend.

In the single experiment of the morning of July 8th, the distribution of the steam in the large cylinder was exactly the same as in the case of the three other experiments; but, in the small cylinder, the steam was cut off when 0 25 of the stroke of its piston was completed, the release and the cushioning being the same as in the three other experiments. Thus the only difference was the changing of the point of cut-off in the small cylinder from

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0·42 to 0·25 of the stroke of its piston from the commencement, whereby the measure of expansion with which the steam was used was made 9.6444 times by volume. The experiments, therefore, enable the determination to be made under equal and unexceptional conditions, and with extreme accuracy, of the economic results due to working high pressure steam in the partially steam jacketed cylinders of a condensing compound engine with pistons moving at a high reciprocating speed, with the measures of expansion 6·2569 and 9 6444 times, by volume. The results are very valuable and far reaching in engineering, and engineers should give them careful consideration and frank acceptance.

The number of pounds of feed water pumped into the boiler, the number of pounds of condensing water admitted to the condenser, and the number of pounds of condensing water and water of condensation withdrawn from the condenser, were obtained by separate measurements in different vessels, and are therefore three independent determinations. The last measurement should give the sum of the two previous ones, and it does so very nearly, the difference being of no practical importance. The very close approximation, however, shows the extreme care taken in the measurements.

The water data of the experiments afford a striking illustration of the transmutation of heat into power. The temperatures of the feed water, and of the condensing water when admitted into the condenser, being known, and the respective weights, the number of units of heat imported to the feed water in the boiler, and the number present in the condensing water and water of condensation when withdrawn from the condenser, are easily calculated, and the difference is the number of units of heat transmuted into the work done in the two cylinders of the engine by the *expanding* steam; that is, into the work done in those cylinders *after* the closing of the cut-off valve of the small cylinder.

An explanation is necessary of the manner in which the horses-power developed by the engine are calculated. Under the head of "horses-power" five kinds will be found in the table, namely, indicated, net, developed by the expended steam alone, total, and delivered by the engine to the factory shafting at the friction brake. The first three and the last are different fractions of the fourth.

The indicated horse-power is computed from the mean indicated pressure given by the indicator diagrams taken from the cylinders, and is given separately for the small and large cylinders, the aggregate being the indicated horses-power developed by the engine.

The main shaft of the engine being disconnected from the factory shafting, and the engine worked *per se*, or unloaded, indicator diagrams were taken at different speeds of piston, and showed that the pressure per square inch of the piston of the small cylinder was 3·627455 pounds, and that the pressure per square inch of the piston of the large cylinder was 1·258947 pounds, and that these pressures were constant for all speeds of piston. They are then the pressures which equilibrate the friction of the moving parts of the engine, and they must be supplied before the pistons can move, so that only what remain of the indicated pressures on the pistons of the two cylinders after the subtraction of respectively these friction pressures, are applied to the crank-pin and do work external to the engine. These remainders are termed the net pressures, and the horses-power calculated from them are termed the net horses-power.

The net horses-power developed by the engine, differs from the horses-power developed by the engine at the brake, by the friction of the load on the moving parts of the engine. When the load, or the factory shafting, is connected to the engine shaft, then a friction is thrown upon the journals and other moving parts of the engine, additional to the friction of the engine, *per se*, and proportional to the load, being a constant per centum of it. Consequently, the horses-power developed by the engine at the brake must be less to the extent of the horses-power required to overcome the friction of the load, than the net horses-power developed by the engine as above computed.

The total horses-power developed by the engine represents the entire work of all kinds performed by the steam, including, of course, the overcoming of the back pressure against the pistons of the two cylinders. This power is composed of the sum of the indicated horses-power developed in the two cylinders and the horses-power required to overcome the back pressure in them against their pistons. Now the pressures for the latter

horses-power are composed of the back pressures against the pistons, *exclusive* of the back pressures of the cushioned steam in the two cylinders. That is to say, the mean of the back pressures from the end of the indicator diagrams opposite the cushioning end up to the point in the stroke of the piston at which the cushioning commenced, is taken for the back pressure, and the length of the stroke of the piston through which the back pressure operates is the length between the same points. Consequently, the horses-power required to overcome the back pressure is calculated for a different stroke of piston than the stroke used for the calculation of the indicated and net horses-power, and different for each cylinder because the cushioning takes place at a different point of the stroke of the piston in each.

The horses-power required to cushion the steam, though expended in overcoming back pressure, is not included as such, because the cushioned steam thus obtained remains in the cylinder—not being exhausted to the condenser—and diminishes by that much the steam drawn from the boiler per stroke of piston. The economic value of this compressed steam, is equal to the compressing power expended upon it, therefore this power is restored during the succeeding stroke of piston by the cushioned steam. If the power expended in cushioning the steam was added to the power expended in overcoming the other back pressure, then the weight of steam so cushioned per stroke of piston, would have to be added to the weight drawn from the boiler per stroke of piston, in order to obtain a proper measure of the cost of the total horse-power. The cost of the indicated and net horse-power is, however, the number of units of heat in the weight of steam drawn from the boiler in a given time, whether there be cushioning or not, or to what extent.

For the small cylinder the calculation of the indicated, net, and total horses-power developed in it, is made for the entire area of its piston, the back pressure being computed down to the zero line. But for the large cylinders the calculations are so made for only the indicated and net horses-power. For the total power, the back pressure down to the zero line is computed as against only the ring or annular area which remains of the piston of the large cylinder after the piston of the small cylinder has been subtracted from it. The reason of this is that the back pressure, due to the piston of the small cylinder, has already been computed down to the zero line.

In the small cylinder, the total horses-power developed by the expanded steam alone, is computed for the mean pressure down to the zero line of the indicator diagram from the point in the stroke of the piston at which the cut-off closed to the end of the stroke, for the entire area of the piston, and for the length of stroke from the point in the stroke of the piston at which the cut-off closed to the end of the stroke.

For the large cylinder, the total horses-power developed by the expanded steam are the sum of the indicated horses-power developed in that cylinder, and of the horses-power expended in overcoming the back pressure, *including* that of the cushioning against the ring, or annular area, which remains of the piston of the large cylinder after subtraction of the piston of the small cylinder, and for the entire stroke of the piston, because all the steam which enters the large cylinder is used expansively from the beginning to the end of the stroke of its piston; and as the question is not horse-power *pro rata* to steam furnished from the boiler, but horses-power absolutely exerted by expanding steam, and for which there is *pro rata* liquefaction of steam in the cylinder, the power expended upon the cushioning must be included.

The cost of the indicated, of the net, of the total horse-power, and of the horse-power developed by the engine at the brake, is given in the table, both in pounds of feed water consumed per hour, and in Fahrenheit units of heat consumed per hour. The first is the measure popularly adopted, because easily expressed, and is sufficiently accurate for practical purposes, but the latter is absolutely correct under all circumstances. The difference in the two measures, for the conditions of ordinary practice, is not great, because the total heat of steam of different pressures within those limits does not vary largely, but the latter measure should be preferred when strict accuracy is needed, as in the case of comparisons. For the present experiments, however, in which the initial pressure upon the piston of the small cylinder, and the back pressure against the piston of the large cylinder, and the temperature of the feed water, varied to only a trifling degree, the difference in the two measures is nearly nothing.

In calculating the quantity of heat transmuted into the horses-power developed by the expanding steam (after the closing of the cut-off valve in the small cylinder), one Fahrenheit unit of heat is

taken as the thermal equivalent of 789¼ foot-pounds of work, which gives 41·811847 Fahrenheit units as the thermal equivalent of one horse-power (33,000 foot-pounds of work per minute); consequently that number multiplied by the number of horses-power developed by the expanding steam and by sixty, the number of minutes in an hour, gives the number of Fahrenheit units of heat transmuted per hour into this horses-power; the quotient of the division of this last product by the latent heat corresponding to the mean pressure of the expanding steam, gives the number of pounds of steam liquefied per hour in the cylinder to produce the horses-power developed there by the expanding steam.

As the experiments of the morning and afternoon of July 7th, and of the afternoon of July 8th, are repetitional, the mean of the three will be taken as expressing the economic results for the conditions under which they were made. The mean of the number of Fahrenheit units of heat imparted to the feed water in the boiler per hour during these experiments, is 1482830·027224. The mean of the number of Fahrenheit units of heat in the mixed condensing water and water of condensation withdrawn from the condenser per hour, is 1265923·565977. The difference is 0·146278 of the larger number.

For the above three experiments, the mean number of pounds of steam condensed per hour in the small and large cylinders, and in the receiver, to furnish the heat transmuted into the total horses-power developed in those cylinders by the expanded steam alone after the closing of the cut-off valve on the small cylinder, is 184·561707. The mean number of pounds of feed water pumped into the boiler per hour, is 1325·845679. The former number is 0·139203 of the latter number.

The difference between the above two determinations (0·146278 and 0·139203) is due to the loss of heat by radiation from the external surfaces of the jet condenser of the engine, and of the measuring tank; and to the fact that the water of condensation resulting from the liquefaction of the steam in the cylinders by the action of the interior surfaces of the latter, contains less heat when revaporized there than when originally vaporized in the boiler. The loss of heat by radiation from the external surfaces of the boiler, steam pipes and cylinders, must not be included in the

above comparison, because such loss is supplied as fast as it occurs by the fuel in the furnace. For the experiments in question, the loss of heat due to the above causes was (0 146278 — 0·139203 =) 0 007075 of the heat imparted to the feed water in the boiler.

For the experiment of the morning of July 8th, in which the steam was expanded 9·6444 times, instead of 6·2569 times as in the other experiments, the number of Fahrenheit units of heat imparted per hour to the feed water in the boiler was 1220557·870799; and the number present in the mixed condensing water and water of condensation withdrawn from the condenser per hour, was 1002735·052380. The difference is 0·178462 of the larger number.

The number of pounds of steam condensed per hour in the small and large cylinders, and in the receiver, to furnish the heat transmuted into the total horses-power developed in those cylinders by the expanded steam alone after the closing of the cut-off valve on the small cylinder, is 162·065479. The number of pounds of feed water pumped into the boiler per hour, is 1081·888922. The former number is 0·149799 of the latter number.

The difference between the above two determinations (0·178462 and 0·1497986) is due to the causes just explained as in the first case, but the loss of heat in this case amounts to (0·178462 — 0·149799 =) 0·028663 of the heat imparted to the feed water in the boiler.

That the loss of heat thus experienced should be proportionally greater in the latter case than in the former, is evident; first, because the loss of heat by radiation from the external surfaces of the condenser and measuring tank is constant for both cases, while the weight of feed water vaporized in the boiler was only eighty-two per centum in the second case of what it was in the first. Further, the cylinder condensations were much greater relatively to the feed water with the larger measure of expansion for the steam, than with the smaller one, and the revaporization of this water of condensation in the second case required less heat proportionally to weight than in the first case, owing to the greater expansion of the steam, and consequently smaller pressures in the cylinders.

The aggregate total horses-power developed by the engine represents the fuel consumed, for that power is the entire

mechanical effect produced by the fuel. Now, of this power, the aggregate net horses-power developed by the engine represents the commercially available part. The mean of the three experiments in which the steam was expanded 6·2569 times, shows that the net power was only 73 16175 per centum of the total power, the remaining 26·83825 per centum being expended in overcoming the back pressures against the pistons and the frictional resistances of the unloaded moving parts of the engine.

The frictional resistance cannot be lessened, but the back pressure can be materially. The back pressure against the piston of the large cylinder is easily understood; it is due to the pressure above zero in the condenser, increased by the resistance caused by the small area of the exhaust port, and by the tortuous passages connected with it. This back pressure can be lessened by larger area of port and by shorter and straighter passage, by a more thorough condensation of the steam, and by a better exclusion of air in leakage, but it will always be something, and any lessening due to more thorough steam condensation is certainly in part, and, under favorable circumstances, perhaps wholly offset by the correspondingly lessened temperature of the feed water. The larger exhaust port will have but little or no disadvantageous effect on the economy of the fuel, if the back pressure be properly cushioned; that is to say, cushioned up to the pressure in the valve chest.

But there is also a corresponding back pressure against the piston of the small cylinder, which is not so well understood, but which is just as injurious to the economy of the fuel as the back pressure against the piston of the large cylinder. This back pressure is the difference between the mean pressure in pounds per square inch above zero, shown by the bottom line of the indicator diagram taken from the small cylinder, exclusive of the cushioning, and the mean pressure in pounds per square inch above zero, shown by the portion of the top line of the indicator diagram taken from the large cylinder, lying between the commencement of the stroke of the piston and the point of cutting off the steam. This difference of pressure is the gap on the indicator diagram formed by properly combining the diagrams of both cylinders, and is caused by the too small areas of the exhaust port of the small cylinder and the steam port of the large cylinder. In the case of the experimental engine, these ports were much too small, and the

back pressure against the piston of the small cylinder was extremely and unnecessarily great.

The per centum of the aggregate total horses-power developed by the engine, transmitted at the brake to the factory shafting, was, as a mean of the three experiments in question, 69·07173, the difference between which and the per centum 73·16175 of the aggregate total horses-power realized as net horses-power is 4·09002 per centum, which is the proportion of the fuel absorbed by the friction of the load. This 4·09002 per centum, if referred to the net horses-power, becomes 5·59 per centum. The coefficient usually allowed is 7·50 per centum.

In the case of the experiment in which the steam was expanded 9·6444 times, the aggregate net horses-power were 71·76471 per centum of the aggregate total horses-power developed by the engine, and the horses-power transmitted at the brake were 69·12477 per centum, the difference 2·63994 is the proportion of the fuel absorbed by the friction of the load, and if referred to the net horses-power becomes 3·68 per centum.

The mean of the three experiments with the steam expanded 6·2569 times, gave the indicated horse-power for 17·103403 pounds of feed water consumed per hour, or for 19128·532189 Fahrenheit units of heat consumed per hour. The experiment with the steam expanded 9·6444 times, gave the indicated horse-power for 16·937819 pounds of feed water consumed per hour, or for 19108·790286 Fahrenheit units of heat consumed per hour. The results by the correct heat measurement are almost identical, and show that no economy of fuel followed increasing the measure of expansion with which the steam was used from 6·2569 to 9·6444 times.

This remarkable determination was obtained for experiments conducted with laboratory exactness by a number of highly educated experts of distinguished reputation, upon an excellent compound engine, and under the most favorable conditions for the large measure of expansion, namely: High initial pressure in the small cylinder, low back pressure in the large cylinder, cut off on both cylinders, and rapid reciprocating speed of piston, the cylinders being partially steam jacketed, and the steam being saturated. Of the truth of the result there can be no doubt, and it furnishes an upper limit for the economical expansion of steam.

When the comparison is made for the net horse-power, and for the total horse-power, the following are obtained: For the net horse-power there were consumed per hour 20717·401634 Fahrenheat units of heat as the mean of the three experiments in which the steam was expanded 6·2569 times; and 21100·310264 Fahrenheit units for the experiment in which the steam was expanded 9·6444 times. In this case, which is that of the commercially valuable horse-power, the smaller measure of expansion was 1·8 per centum more economical than the larger measure. For the total horse-power there were consumed 15157·303944 Fahrenheit units of heat as the mean of the three experiments in which the steam was expanded 6·2569 times; and 15142·576895 Fahrenheit units for the experiment in which the steam was expanded 9·6444 times; or almost exactly the same as with the lesser measure of expansion.

The calculated results from the experimental data show why the greater measure of expansion for the steam failed to produce any greater economy of the fuel than the lesser measure. The mean of the three experiments in which the steam was used with the lesser measure of expansion, shows that 24·777623 per centum of the steam entering the small cylinder remained condensed to water in it when the cut-off valve closed; and that in the experiment made with the larger measure of expansion, 43·813874 per centum of the steam which entered the small cylinder remained in it condensed to water when the cut-off valve closed.

The revaporization of the above water of condensation in the small cylinder under the lessening pressure due to the expanding steam, and at the expense of the heat in the metal of the cylinder and in the water of condensation, reduced the amount of condensation at the end of the stroke of the piston to 6·572403 per centum of the steam entering the small cylinder, for the smaller measure, of expansion; and to 11·674740 per centum for the larger measure. These percentages of water were revaporized in the small cylinder under the less pressure of the receiver when the exhaust valve opened, at the expense of the heat contained in the metal of the cylinder and contained in the water above the temperature due to the lessened pressure, and the steam thus produced passed into the receiver during the exhaust stroke of the piston, so that all the steam which entered the small cylinder finally passed into the larger one.

At the end of the stroke of the piston of the large cylinder, the water remaining in it due to the condensation of the steam, was 7·296654 per centum of the steam evaporated in the boiler for the smaller measure of expansion, and 10·521183 per centum for the larger measure of expansion, and these percentages of water were revaporized in the large cylinder under the less pressure of the condenser when the exhaust valve opened, and passed into the condenser during the exhaust stroke of the piston; the heat producing this revaporization being that which was contained in the metal of the cylinder and in the water of condensation. Of course, no work is obtained from the steam of the revaporized water of condensation that passes to the condenser during the exhaust stroke of the piston of the large cylinder, but the metal of the cylinder is chilled by this revaporization, so that it acts as a condenser to the next charge it receives from the small cylinder.

The re-evaporated steam which passed from the small cylinder to the large one during the exhaust stroke of the piston of the former, was utilized upon the piston of the latter, and by fitting the large cylinder with a lap cut-off steam valve, this re-evaporated steam was used expansively in that cylinder. The economic superiority of the compound engine over the simple one worked between the same boiler and condenser pressures, with the same measure of expansion and the same reciprocating speed of piston, is due to the fact that the steam condensed in the small cylinder by the interaction of its metal, is used upon the piston of the large one during its whole stroke, and expansively, too, if a cut-off be applied there.

The discovery that the cylinder of a steam engine acted alternately as a condenser and as a boiler, condensing a portion of the entering steam during its admission and revaporizing the resulting water of condensation during the period of expansion and during the exhaust stroke, which phenomena were caused wholly by the interaction of the metal of the cylinder, and would not have happened had the cylinder been constructed of a material which neither received nor imparted heat, was made a great many years ago by the writer, and stated and used in his published professional writings.* No one contested the discovery, or even used it, until

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* Engineering Precedents. Vol. 2. 1859. Experimental Researches in Steam Engineering. 1861 and 1863.

quite lately; in fact, it was not for a long time believed. The discovery was made and proven in the only way possible, namely, by weighing the water fed into the boiler, and ascertaining, by means of the indicator, the weight of steam present as such in the cylinder at the point of cutting off and at the end of the stroke of the piston, adding to the last quantity the weight of steam condensed in the cylinder to furnish the heat transmuted into the power developed by the expanding steam, the latter obtained also by means of the indicator. The difference between the weight of water fed into the boiler and the weight of steam accounted for by the indicator at the above two points of the stroke of the piston, is the weight of steam condensed in the cylinder at those points by the interaction of the metal of which it is made. Of course, this quantity is to be slightly diminished by the weight of steam condensed in the steam pipe, valve chest and cylinder by external radiation. This, however, is unimportant in well-clad pipes and cylinders. If the water of condensation in the steam pipe flows back to the boiler instead of on into the cylinder, as it may do in whole or in part, depending on the inclination of the pipe and the velocity of the steam current, the allowance for the condensation by external radiation will be lessened that much.

No investigator other than the writer ever made experiments in this manner for a great many years after 1859, nor thought of ascertaining by measurement the difference of the weight of steam as given by the indicator and by the weight of water fed into the boiler, nor dreamed of attributing that difference to the interaction of the metal of the cylinder. The only cylinder condensation suspected was that which is obviously due to external radiation, and is a mere trifle under the conditions of good practice. This is the crucial point, and before any other experimenter can substantiate a claim to the discovery of cylinder condensation by the interaction of the metal of the cylinder, he must show the previous publication of an experiment in which that condensation is deduced from the comparison of the weight of steam accounted for by the indicator and the weight of water fed into the boiler. The writer is well acquainted with the literature of his profession, and is very confident that no such publication can be produced.

The writer made and published many such experiments in all their details on engines of different sizes and designs, deducing

from them, and for the first time, what may be called the *physiology* of the steam engine, as distinguished from an abstract mathematical conception of its theory, which had been exclusively in vogue before his work was given to the public, and still is largely accepted by professors; but his results, though now generally adopted by engineers, were for a great many years ignored, or rather silently disbelieved by all, because contrary to the then received ideas on the subject. Occasionally, some sorry attempts were made to ridicule them, but no one came forward to sustain the writer, much less to dispute his pretensions. The fact is, that for many years he stood alone. Not only was he not antedated in his discoveries, but no one seems for a long time after they were published with their full experimental proofs, to have understood them, or the important inferences deducible from them. Yet without the great underlying fact of cylinder condensation due to the interaction of the metal of the cylinder, there can be no correct theory of the steam engine; for without it there cannot be understood how the economy of the power, other things equal, is so greatly affected by mere size of cylinder as it is, becoming less as the size of the cylinder becomes less: how, other things equal, the economy of the power is affected by the reciprocating speed of the piston, becoming less as that speed becomes slower; how the gain theoretically due to greater measures of expansion for the steam, is not practically realized, the cylinder condensation increasing with increased measures of expansion, until the increased loss of steam by this condensation soon equals the gain due to the increased measure of expansion. Steam condensation in the cylinder by the interaction of its metal explains, and furnishes the only explanation of the economy to be derived from using superheated steam, from using steam jackets for the cylinders, and from compounding the cylinders.

The writer very early pointed out how quickly the limit of economy was reached by the expansion of saturated steam in a single cylinder, gave the reason therefor, supported it by abundant experimental proofs, and saw it rejected by every one for many years, and by many even now. He not only stated the facts qualitatively, but he experimentally gave the quantitative determinations for a great variety of cases. All that incredulity had to do was to repeat his experiments, but it was found much easier and

more agreeable to ignore them. In the few test repetitions that have been made, as in the present experiments, the writer's results were always reobtained, but the experimenters seemed to lack faith in their own work, and to think that some incomprehensible error had produced them.

No theory of the steam engine can have any value which is not based on the great fact of cylinder condensation by the interaction of the metal, and on the variations in the quantity of that condensation due to different conditions. Nothing else will explain the results of steam engineering; and here, as everywhere in industrial art, the properties of matter must be considered in connection with abstract laws, if practical results are to be correctly predicted, or even understood.

There is, perhaps, a necessity for stating that cylinder condensation by the interaction of the metal, is a totally different thing from the condensation in the cylinder of a portion of the steam to furnish the heat transmuted into the power developed by the expanding steam after the closing of the cut-off valve, because the late Professor Rankine, some years before his death, in a letter to the London *Engineer*, confused the two, and, knowing nothing of the former, seemed to think that by it the latter was meant.

In the following, Table No. 2, are given the data and results of the experiments made with the engine doing its regular work on two succeeding days, and continuing through the working hours of each, to test the accuracy of the results in Table No. 1, as it was supposed that a lengthened trial might give values different from those of a short one. The conditions for the experiments in both tables were sensibly the same, and so were the economic results.

Table No. 2, containing the data and results of the experiments made on the 22d and 23d of October, 1879, on a condensing compound engine, while doing its regular work in the factory of Mr. Antoine Herzog, at Colmar, in Alsace, Germany, by the Committee on Mechanics of the Industrial Society of Mulhouse, to ascertain the cost of the indicated horse-power in pounds of feed water consumed per hour:

| | October 22, 1879. | October 23, 1879. |
|---|---|---|
| Duration of the experiments in consecutive hours and decimals of an hour, . . . . . . . . . . . . . . . . . . . . . . . . . | 12·3125 | 12·3403 |
| Total number of double strokes made by the pistons of the engine, | 65479·0000 | 65509·0000 |
| Total number of pounds of feed water pumped into the boiler, . . | 14095·0258 | 13922·4040 |
| Steam pressure in the boiler in pounds per square inch above the atmosphere, . . . . . . . . . . . . . . . . . . . . . . . . | 88·675 | 87·908 |
| Number of double strokes made per minute by the pistons of the engine, . . . . . . . . . . . . . . . . . . . . . . . . . . . | 88·634856 | 88·475699 |
| Number of pounds of feed water consumed per hour, . . . . . . . | 1144·773669 | 1128·206283 |
| Pressure on the piston of the small cylinder at the commencement of its stroke in pounds per square inch above the atmosphere, . | 78·119 | 78·909 |
| Mean indicated pressure on the piston of the small cylinder in pounds per square inch, . . . . . . . . . . . . . . . . . . . | 28·255 | 28·944 |
| Mean indicated pressure on the piston of the large cylinder in pounds per square inch, . . . . . . . . . . . . . . . . . . . . | 18·311 | 17·976 |
| Mean back pressure against the piston of the large cylinder, exclusive of cushioning, in pounds per square inch above zero, . . | 2·697 | 2·470 |
| Indicated horses-power developed in the small cylinder, . . . . . | 23·113339 | 23·634452 |
| Indicated horses-power developed in the large cylinder, . . . . . | 43·191937 | 42·325622 |
| Aggregate indicated horses-power developed by the engine . . . . | 66·305276 | 65·960074 |
| Number of pounds of feed water consumed per hour per indicated horse-power developed by the engine, . . . . . . . . . . . . . | 17·265197 | 17·104382 |

Hanging of Charts, Diagrams, Etc., for Display, Preservation, Etc.—In hanging charts, diagrams, maps, etc., for illustration of lectures, preservation, etc., a great desideratum is ease of removal, and substitution of others. Various devices, involving frames, pulleys, step-ladders, etc., have been employed, but the plan adopted by Professor Himes of Dickinson College, in the new Jacob Tome Scientific Building, seems to be peculiarly simple, effective, and cheap. As supports, wires are drawn around the room about six inches from the ceiling, or fourteen feet from the floor, fixed in eyelet screws, and supported at intervals as may be necessary, by means of screw hooks. Similar wires are drawn behind the lecture stand at intervals of several feet.

The diagrams are attached to strips of wood about a quarter-of-an-inch thick and an inch wide, by means of a spring clothes-clip at each end. One side of each of the clips is supplied with a hook made by a wire passed through it, and bent. An eyelet screw, of about one-half inch opening, is screwed into the middle of the strip, in front, through the chart, or the latter may be notched. By means of a wooden rod of suitable length, with a pin projecting about an inch from the end, thrust through the eyelet, the whole can be readily raised above the wire so as to bring the hooks down upon it. In a similar manner it can be taken down ; the changing of the diagrams involving less trouble than by direct handling, and for simple preservation, several may be hung up on each other. The strip is readily removed, especially if the chart is notched, and the latter can be preserved in any other way. By a similar plan, suspensions from the ceiling for different purposes can be as readily made.

# CYLINDER CONDENSATION IN STEAM ENGINES. AN EXPERIMENTAL INVESTIGATION.

BY CHAS. L. GATELY, M. E., AND ALVIN P. KLETZSCH, M. E.

[*Presented to the American Association for Advancement of Science; Ann Arbor Meeting, 1885, with an Introduction by* PROFESSOR R. H. THURSTON.]

## INTRODUCTION.

In a paper read by the writer before the New York Academy of Sciences, several years ago,* the remark was made, referring to the nature of that function which determines the waste by "cylinder condensation:" "The function is evidently determined by the area of cylinder surface, time of exposure, variation of temperature of surfaces and quantity and character of the working steam."

The writer was compelled to assume the form of this function, and, after studying existing records of experiments, concluded that it was practically correct to take the amount of loss due to the cause above referred to as varying as the square root of the ratio of expansion. But, as remarked later, † "a comparison of the quantities of steam demanded to supply an engine thermodynamically 'perfect' with the actual quantities required by even the best of engines exhibits so wide a difference that it becomes obvious that the determination of the efficiency of an engine and the solution of the questions involving those of expenditure of heat are not problems in thermodynamics simply. The mathematical theory of the steam engine is not yet in so satisfactory a state—and cannot be until the correct theory of this transfer of waste heat can be introduced into it—that the engineer can often use it in every-day office work with much confidence, unless checked by direct experiment."

* "On the Behavior of Steam in the Steam Engine Cylinder, and on Curves of Efficiency;" JOURNAL OF THE FRANKLIN INSTITUTE, February, 1882.

† "On the Several Efficiencies of the Steam Engine, and on the Conditions of Maximum Economy." Trans. Am. Soc. of Mechanical Engineers, April, 1882; JOURNAL OF THE FRANKLIN INSTITUTE, May, 1882.

It had been the intention of the writer, for a long time previous to the publication of the paper referred to above, and of several other papers published at other dates, bearing upon the same general subject, to seek an opportunity to make a systematic investigation of this whole subject, and to determine, if possible, the laws governing the variation and the amount of cylinder condensation in steam engines, the speed of piston, the area of exposed surfaces, the ratio of expansion and the pressure of steam and its temperatures, varying within the range of familiar practice. It is not unusual to find steam engines in common use in which the speeds of piston vary from 200 up to 600 feet, or more, per minute, and 1,000 feet is becoming a not very unusual speed. Steam pressures range from twenty-five to 250 pounds per square inch in this country, and from two to ten atmospheres in Europe, while in exceptional cases, the pressures are vastly higher than the larger of the figures just given. The ratio of expansion varies from about two, in low pressure and the simpler kinds of engines, to ten, or even twenty, with high steam and superheating in machines designed with the intention of securing the utmost possible efficiency of fluid. In the latter, also, it is usual to find condensers in which a vacuum of twenty inches (two-thirds of one atmosphere) is maintained, in utter disregard of the fact that high temperatures of steam should be accompanied by a restricted amount of vacuum, and a warm condenser. The area of surface presented to the steam varies from about one square inch per pound of water per hour, in very small engines, to, perhaps, one quarter as much, in very large marine engines.

Before the date of the research to be described in the following paper, much had been done in this line of investigation, and some facts had been settled with a practically satisfactory degree of certainty. The work of Messrs. Clark, in England, and Hirn, in France, had shown the importance of this phenomenon of cylinder condensation, in the economy of the engine, and had given us some knowledge of the extent to which it affected the efficiency of certain classes of engine. The investigations of Isherwood had shown very clearly the extent, and the method of variation, of this waste, with varying ratios of expansion, in the marine engine of which that of the United States Steamship *Michigan* is the type. The studies of Escher had indicated the method of variation with

change of speed of piston; and other investigators had added something to the existing stock of knowledge. The writer, however, in common with many others in the profession, was desirous of securing an opportunity to investigate the matter more completely, and more systematically, than it had yet been possible, and sought to find a means of carrying out a plan which he had long before laid out. It was his desire to make an investigation upon an engine of fair size, of ordinary commercial construction, and under the usual conditions of every-day operation, first determining upon some one condition which should be made variable, all others being retained constant, then making this first condition constant, and another variable, and thus, one by one, determining the influences which, together, determine the total effect, measuring the extent of that effect, and learning the law of its variation. Thus it would be possible to ascertain the effect of variation of each of the determining conditions, as above, and to ascertain, and to express, the law of such variations, and the final resultant of all. To do this work properly required, evidently, great care, skill, patience, and familiarity with the steam engine and its management, and demanded a corresponding familiarity with the use of the apparatus of exact measurement to be applied in the work.

Such an opportunity finally offered, in the spring of 1884, when Messrs. Gately and Kletzsch, two young men who were attached to the Stevens Institute of Technology, found it possible to obtain an engine of 250 horse-power for purposes of experiment. An investigation, such as is above outlined, was at once planned, and was carried out during the later part of the spring and in the early summer of that year, and the results, as here given, were subsequently worked up as time and opportunity permitted, in such intervals of their business life as could now and then be secured by those engaged in the work.

Messrs. Gately and Kletzsch designed a "prony brake," which proved to be thoroughly well adapted to the very heavy work required of it, and which ran smoothly and successfully up to some 300 horse-power, a power which the writer had never before known to be applied to any brake controlling a steam engine. A weir was constructed, with which to measure the quantity of water of condensation, and the investigators were supplied with all needed

indicators, meters, thermometers and other apparatus from the Mechanical Laboratory of the Stevens Institute of Technology, then in charge of the writer, who had organized it for such purposes, as well as for commercial investigations, some years before. The work of investigation was performed mainly by the two gentlemen, who had assumed charge of this very important task. Fortunately, both had had experience in the use of instruments, such as were required in the work, both having been trained in the laboratories and the experimental department of the college, and Mr. Kletzsch having prepared himself with a view to taking charge of the mechanical laboratory of the Institute, a position which he has occupied up to the present time. They were aided by other trained assistants detailed from the college, and especially by Professor C. A. Carr, of the United States Naval Engineers, who, at that time, was on duty at Hoboken, as Professor of Marine Engineering and as Assistant Professor of Mathematics. The whole work was very carefully planned, the observations were made with great care and abundant skill, and the manner in which they have been worked up is evidence, equally, of the reliability of the observations, and of the ability with which the whole research was conducted and completed.

The results will be found of peculiar value and interest. In some cases, they confirm, in a very satisfactory manner, work previously done by the earlier investigators already referred to, and, in other instances, they give us entirely new and strikingly important deductions. The method taken of deriving these results, by a union of mathematical and graphical methods, will be seen to give great certainty, as well as to present the laws established in a manner which is most thoroughly satisfactory to the reader and to the investigator who may desire to make use of them in further research.

The whole report, as presented, finally, to the writer, is here given, as originally prepared, and is so complete in detail, and so well constructed, that it is unnecessary here to go into explanation, or to give a *résumé* of its conclusions. It will be observed that the method of variation of cylinder condensation, with variation of the ratio of expansion, is found to be precisely that indicated in earlier papers presented by the writer, and assumed in the theory of efficiency developed by him. The variation of condensation, with

changes of pressure and temperature, under usual conditions of practice, is found to be very moderate, and to follow a very simple law, so far as it can be traced. The waste with varying speed of engine is found, also, to be nearly as indicated by earlier writers; but the law is less exactly determined than in the case of varying expansion. Since, however, in all ordinary cases, in practice, the speed of engine and the boiler pressure are practically constant, in the regular operation of the engine, the most important part of the investigation is that relating to the ratio of expansion, which part of the work is most satisfactorily fruitful of result. The next most important matter is the determination of the variation of loss with varying speed of engine, and the results here reached are sufficiently exact to be very useful, both to the designer and the owner of engines; while the last investigation, that relating to variation with change of pressures, is very interesting as bearing upon the future of the now progressing advance in the direction of increasing pressures. The last two lines of research demand still further and corroboratory exploration. The results here reached must be regarded as applicable, in the theory of the steam engine. only provisionally, and as to be accepted finally, only after repeated experiment with other sizes and kinds of engine. This investigation, although most complete in plan and systematic in its prosecution, is but a single step in the work.

R. H. THURSTON

SIBLEY COLLEGE,
CORNELL UNIVERSITY, *Ithaca, N. Y., July 1, 1885.*

## CHAPTER I.

### OBJECT OF THIS RESEARCH.

The loss or waste, known as cylinder condensation, which occurs in the working of all steam engines, has been recognized by engineers as a more or less important factor, entering into the design of an engine ever since the time of Watt.

The solution of the problem of the method of variation of this condensation was suggested to the writers in the spring of 1884, by Professor R. H. Thurston, then of the Stevens Institute of Technology, Hoboken, N. J., as a most promising field for investigation in the department of steam engineering, not only from the fact of its vast importance to steam consumers at large, but also, because the best data existing on the subject were very incomplete and unsatisfactory.

Up to that time, although the general method of action was fairly well understood, the amount of loss which would occur from this cause with any given set of conditions, could not be predicted with that certainty which is essential in the designing of an engine. Thus we were led to the consideration of this question, and to attempt its experimental investigation. Our principal object was to furnish to the engineering profession a complete set of data, obtained from a good factory engine, running under conditions which were completely under our control, and such as to enable us to vary at pleasure the three most important factors entering into this question, viz., the ratio of expansion, the pressure and the piston speed.

Further than this, we desired to deduce the laws affecting this loss from a series of careful observations of the conditions governing each particular case of initial condensation.

Our limited time has rendered it necessary that several of the parts into which the subject might be subdivided should be left untouched, hence it is that we have given in considerable detail the construction of the special apparatus used, its arrangement when in use, a description of the engine, and the manner in which the trials were conducted, so that any one who may see fit to use the data here furnished, can satisfy himself as to its true value, with a better knowledge of all the details attending the trials, than he could get by simply an examination of the records of the observations.

I. CYLINDER CONDENSATION DEFINED—ITS METHOD OF ACTION.

As some difference of opinion still exists as to just how condensation takes place within the cylinder, and as to its causes, we may quote from several well-known authorities on the subject, in order that the different opinions of eminent engineers may be compared with results obtained by us, and which will be found summarized later.

Professor Rankine, in his "Steam Engine and other Prime Movers," pages 395–396, writes: "That liquefaction does not, when it first takes place, directly constitute a waste of heat or of energy; for it is accompanied by a corresponding performance of work. It does, however, afterwards, by an indirect process, diminish the efficiency of the engine; for the water which becomes liquid in the cylinder, probably in the form of mist and spray, acts as a distributor of heat, and equalizer of temperature, abstracting heat from the hot and dense steam during its admission into the cylinder, and communicating that heat to the cool and rarefied steam which is on the point of being discharged, and thus lowering the initial pressure and increasing the final pressure of the steam, but lowering the initial pressure much more than the final pressure is increased; and so producing a loss of energy, which cannot be estimated theoretically."

Professor Jas. H. Cotterill, in his treatise on "The Steam Engine Considered as a Heat Engine," page 246, says:

"When the volume of steam actually delivered from a steam cylinder at release is compared with the volume of dry steam at the terminal pressure, corresponding to the amount of feed water used, it is always, or nearly always, found that the first is far less than the second, showing that at the end of the stroke the steam discharged from the cylinder must contain more or less water, which is either re-evaporated during exhaust, or is carried out with the exhaust steam in the shape of suspended moisture.

"Some of this is no doubt due to the fact that the steam supplied by the boiler is rarely dry, but in general the difference in question is far too great to be thus accounted for, and it is, therefore, necessary to suppose that liquefaction takes place after the steam enters the cylinder. Moreover, when the expansion curve drawn by an indicator is examined, it is almost always found, even when

the greatest care has been taken to eliminate the disturbing causes, to show that evaporation takes place during expansion.

"Now these unquestionable facts can only be explained by supposing that liquefaction takes place during the admission of the steam to the cylinder, and evaporation during expansion and exhaust.

"This alternate liquefaction and evaporation is chiefly due to the action of the sides of the cylinder, in many cases combined with the effect of water remaining in the cylinder after exhaust is completed.

"It is in the first place clear that the amount of steam liquefied on admission must depend on the area of the surface exposed to the steam. It is true that other circumstances may, or rather must, have influence, and especially the time during which the contact of the steam with the surface lasts, and the temperature of the surface; but the first consideration is the actual area of the surface."

Referring to Chief Engineer Isherwood's report of the Marine Engine trial, made by a board of Naval Engineers, Professor Cotterill continues:

"We may draw the following conclusions from them:

"(1.) The initial condensation, and the heat absorbed per square foot of admission surface, increase with the ratio of expansion.

"(2.) The initial condensation at high rates of expansion may exceed fifty per cent."

Professor Thurston writes: *

"Of all the heat furnished to the engine by the boiler, a certain part, definite in amount and easily calculated, when the power developed is known, is expended by transformation into mechanical energy, another part, equally definite, and easily calculated, also, is expended as the necessarily occurring waste which must take place in all such transformations, at ordinary temperatures of reception and rejection of heat; still another portion is lost by conduction and radiation to surrounding bodies; and finally, a part, often very large in comparison with even the first and most important of these quantities, is wasted by transfer within the

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* "On the Several Efficiencies of the Steam Engine;" Trans. Am. Soc. of Mechanical Engineers; JOURNAL OF THE FRANKLIN INSTITUTE, 1882.

engine from the induction to the eduction side, or from 'steam to exhaust' without any useful effect being derived therefrom. This last transformation is what is properly known as cylinder condensation.

"The amount of this loss increases with wet steam, and is diminished by any expedient, as steam jacketing, or super-heating, which prevents the introduction or production of moisture in the midst of the mass of steam in the cylinder.

"It is generally assumed, in the usual theory of the engine, that the expansion of the working fluid takes place in a cylinder having walls impermeable to heat, and in which no losses by conduction or radiation can occur; but it is impossible, in practice, so far as is known, to secure a working cylinder whose material will fulfil these conditions. The consequence is, that since the steam or other working fluid enters at a high temperature, and is discharged at a comparatively low temperature, the surfaces of the cylinder, cylinder heads and piston are one moment charged with heat of a high temperature, and at the next instant exposed to lower temperatures, are drained of their surplus heat, which heat is then rejected from the cylinder through the exhaust and wasted. In the steam engine, the loss by the method here referred to is rarely less than one-fourth, in unjacketed cylinders, and is often more than equal to the whole quantity of heat transformed into mechanical energy.

"As the range of temperature worked through in the engine increases as the quantity of steam worked per stroke diminishes, and as the time allowed for transfer of heat to and from the sides and ends of the cylinder and piston is increased, the magnitude of this loss increases. Hence the use of high steam of a high ratio of expansion, and of low piston speed, tend to increase the amount of this waste."

2. INFLUENCE OF CYLINDER CONDENSATION UPON EFFICIENCY—METHOD OF SECURING ECONOMY—INFLUENCE ON THE RATIO OF EXPANSION AT MAXIMUM EFFICIENCY.

By reference to Table I, line 31, it will be seen that, of all the steam that passed into the cylinder from the boilers, from twenty-two to fifty per cent. absolutely passed through the engine to the exhaust without producing any useful dynamical effect upon the

piston. From this it can readily be understood at what point the engine of the present day fails, and why so small a percentage of the energy stored in the fuel consumed by the boilers is realized in giving motion to the machinery of our mills. Any saving effected in this direction would be felt throughout the world in the cheapening of the manufactured products, and he who accomplishes it will be considered as great a public benefactor as he who first conceived the idea of utilizing the steam itself.

In considering the theory of the steam engine thermodynamically, expansive working of the steam is found to produce economy, but the effect produced by cylinder condensation is not considered, hence it is that the extent to which expansion should in theory be carried is found to be greatly in excess of that found to give the best results in practice. This can readily be understood by referring to *Plate I*, when it will be seen that, as the ratio of expansion increases, or as the fraction of the stroke completed up to cut-off diminishes, the percentage of condensation rapidly increases, the angle made by the curve representing the variation with the axis of X, on which the percentage of condensation is laid off, becoming less and less as the cut-off is earlier. Therefore, a point must exist at which, expansion being carried beyond it, the loss due to condensation will exceed the gain of work done by the expanding fluid.

Professor Thurston, in a paper on the "Several Efficiencies of the Steam Engine," read before the American Society of Mechanical Engineers, Philadelphia, 1882,* writes: "The efficiency of engine has been often studied by authorities considered as standard, but almost invariably as a problem in thermodynamics, simply; and the losses of heat occurring in consequence of the working of steam in a cylinder composed of a good conductor of heat have been left unnoted, although frequently the most important of all the expenditures of heat taking place in the engine.

"In a non-conducting cylinder, the maximum efficiency of fluid would be secured if the ratio of expansion were made nearly the quotient of initial by back pressure; while the efficiency of the en-

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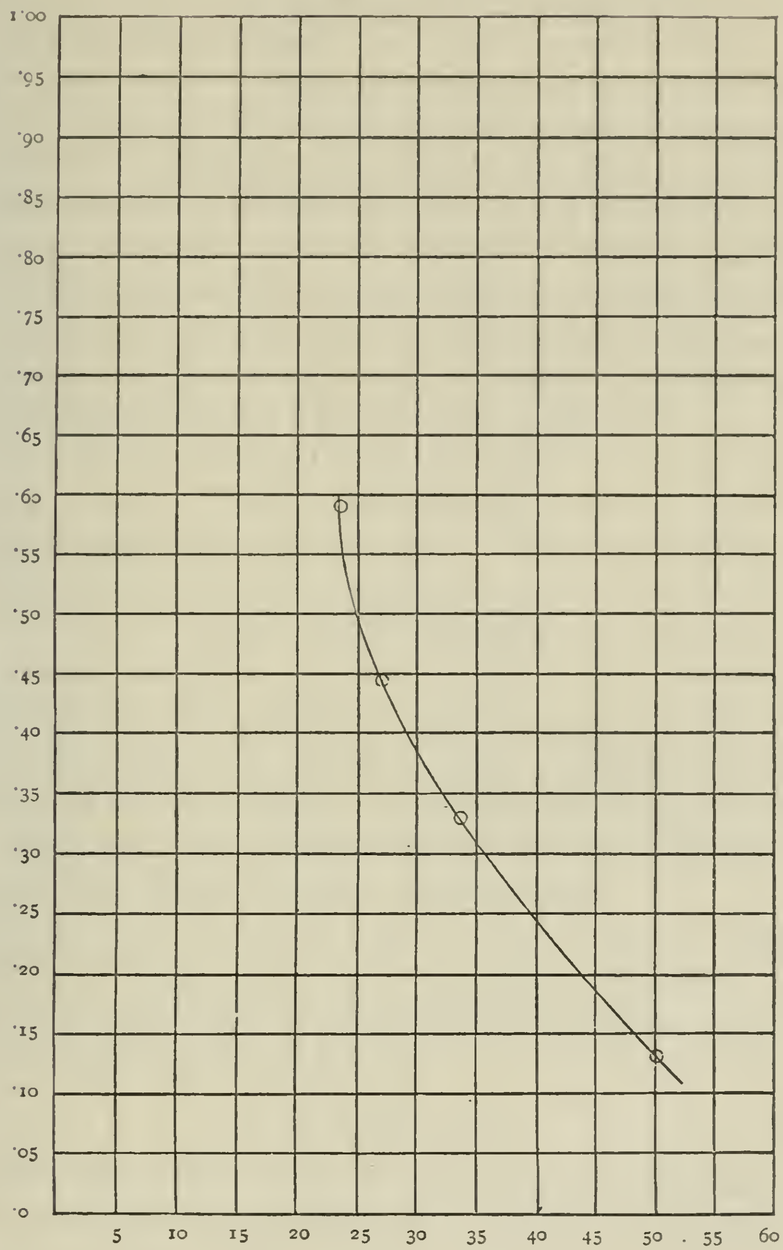
*Trans. Am. Soc. of Mechanical Engineers, 1884; JOURNAL OF THE FRANKLIN INSTITUTE, 1882.

PLATE I.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gine would be made a maximum when the ratio is made nearly equal to the quotient of initial pressure by the sum of all useless resistances. When, however, as is always the case in practice, the steam is worked in a metallic cylinder, the best ratio of expansion is made very much smaller, and the efficiency of the engine is greatly reduced by cylinder condensation and re-evaporation, which produce a serious waste of heat.

"The total loss of efficiency of work, or of pressure, due to cylinder condensation may be allowed for by taking for its value the expansion $a\ r^{m}$, in which $a$ is a constant dependent upon the state of the steam before expansion, $r$ is the rate of expansion, and $^{m}$ is an exponent dependent upon the method of variation of the properties of the mixture of steam and water as expansion progresses.

"The useful work per stroke is a maximum, and the ratio of expansion at maximum efficiency of engine is found, when the latter is of such value as to satisfy the equation:

$$r^{-n} - a\ r^{m-n} = \frac{p_b}{p_1},$$

nearly, and when, if $c$ is the 'cut-off,'

$$c^{n} - a\ c^{n-m} = \frac{p_b}{p_1},$$

nearly.

"The value of the constant $a$ varies from 0·1 to 0·2, in good engines, according to the quality of steam supplied, and $^{m}$ may be taken at $o$ in the best class of well-designed compound engines, and as rising to 0·5 in unjacketed single cylinder engines; $^{n}$ is the exponent in the equation of the expansion line."

Reference will be made later to the "curve of efficiency," described by Professor Thurston in the paper referred to, by which he represents graphically the general effect produced by condensation at varying ratios of expansion.

### 3. HISTORICAL, ETC.

In order to be brief and at the same time not wishing to underrate the work done by physicists and engineers previous to our time, we will quote, from Dr. R. H. Thurston's "Theory of the Steam Engine,"* the following historical outline:

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* Report of British Association for Advancement of Science, Montreal Meeting, 1884; printed in extenso, p. 569.

"The limitations of the thermodynamic theory of the heat engines, and of its application in the design and operation of such engines, were first discovered by James Watt a hundred years ago and more. They were systematically and experimentally investigated by Isherwood, in 1855 to 1865, were observed and correctly interpreted by Clark in 1855 and earlier, and were revealed again by the experiments of Hirn, and by those of Emery and many other recent investigators on both sides of the Atlantic. These limitations are due to the fact that losses occur in the operation of steam engines which are not taken into account by the hitherto accepted theory of the engine, and have no place in the thermodynamic treatment of the case.

"James Watt discovered this cause of the limitation of the efficiency of the steam engine. He not only discovered the fact of the existence of this method of waste, but experimentally determined its amount in the first engine ever placed in his hands. It was in 1763, that he was called upon to repair the little model of the Newcomen engine, then and still in the cabinets of the University of Glasgow. Making a new boiler, he set up the machine and began his experiments. He found, to his surprise, that the little steam cylinder demanded four times its own volume at every stroke, thus wasting, as he says, three-fourths of the steam applied, and requiring four times as much 'injection water' as should suffice to condense a cylinder full of steam. It was in the course of this investigation that he discovered the existence of so-called 'latent heat.' All of Watt's first inventions were directed toward the reduction of this immense waste. He proposed to himself the problem of keeping the cylinder 'as hot as the steam that entered it;' he solved this problem by the invention of the separate condenser and the steam jacket, and thus the discovery of the limitation of the thermodynamic theory here noted was the source of Watt's fame and fortune.

"John Smeaton, a distinguished contemporary of Watt, and perhaps the most distinguished engineer of his time, seems to have been not only well aware of this defect of the steam engine, but was possibly even in advance of Watt in attempting to remedy it. He built a large number of Newcomen engines between 1765 and 1780, in some, if not many of which, he attempted to check loss by this now familiar 'cylinder condensation' in engines, some

of which were five and six feet in diameter of cylinder, by lining pistons and heads with wood. This practice may not be practicable with the temperatures now usual; but no attempt has been made, so far as is known to the writer, to follow Smeaton in his thoroughly philosophical plan of improvement. Cylinder condensation remains to-day, as in the time of Smeaton and Watt, the chief source of waste in all well-designed and well-constructed heat engines.

"It is a curious fact, and one of great interest as illustrating the gulf formerly separating the philosopher studying the steam engine and working out its theory from the practitioner engaged in its construction and operation in the earlier days of engineering, that, notwithstanding the fact that this waste was familiar to all intelligent engineers, from the time of the invention of the modern steam engine, and was recorded in all treatises on engine construction and management, the writers on the theory of the machine have apparently never been aware that it gives rise to the production, in the working cylinder, of a large amount of water mingled with the steam. In fact, it has often been assumed by engineers themselves that this water is always due to 'priming' at the boiler. Even Rankine, writing in 1849–50, while correctly describing the phenomenon of cylinder condensation, made the mistake of attributing the presence of the water in steam cylinders to the fact of condensation of dry steam doing work by expansion, apparently not having noted the fact, that this would only account for a very insignificant proportion of the moisture actually present in the average steam engine. He considers incomplete expansion the principal source of loss, as do usually other writers on thermodynamics.

"Thomas Tredgold, writing in 1827, who, but little later than Carnot, puts the limit to economical expansion at the point subsequently indicated and more fully demonstrated by De Pambour, exaggerates the losses due to practical conditions, but evidently does perceive their nature and general effect. He also shows that under the conditions assumed, the losses may be reduced to a minimum, so far as being dependent upon the form of the cylinder, by making the stroke twice the diameter.

"The limit of efficiency in heat engines, as has been seen, is thermodynamically determined by the limit of complete expansion. So well is this understood, and so generally is this assumed to

represent the practical limit, by writers unfamiliar with the operation of the steam engine, that every treatise on the subject is largely devoted to the examination of the amount of loss due to what is always known as 'incomplete expansion'—expansion terminating at a pressure higher than the back pressure in the cylinder. The causes of the practical limitation of the ratio of expansion to a very much lower value than those which maximum efficiency of fluid would seem to demand, have not been usually considered either with care or with intelligence by writers thoroughly familiar with the dynamical treatment, apart from the modifying conditions here under consideration.

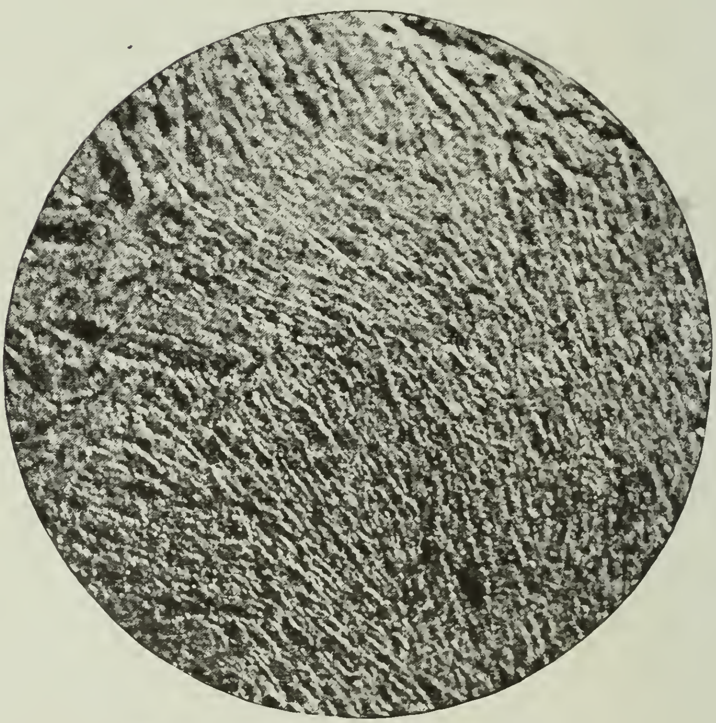
"Watt, and probably his contemporaries and successors, for many years supposed that the irregularity of motion due to the variable pressure occurring with high expansion was the limiting condition, and does not at first seem to have realized that the cylinder condensation, discovered by him, had any economical bearing upon the ratio of expansion at maximum efficiency. It undoubtedly is the fact that this irregularity was the first limiting condition with the large, cumbrous, long-stroked, and slow-moving engines of his time. Every accepted authority from that day to the present has assumed, tacitly, that this method of waste has no influence upon the value of that ratio, if we except one or two writers, who were practitioners rather than scientific authorities.

"Mr. D. K. Clark, publishing his *Railway Machinery*, in 1855, was the first to discuss this subject with knowledge, and with a clear understanding of the effects of condensation in the cylinder of a steam engine upon its maximum efficiency. Cornish engines, from the beginning, had been restricted in their ratio of expansion to about one-fourth as a maximum, Watt himself adopting a 'cut-off' at from one-half to two-thirds. Hornblower, with his compound engine competing with the single cylinder engines of Watt, had struck upon this rock, and had been beaten in economy by the latter, although using much greater ratios of expansion; but Clark, a half century and more later, was the first to perceive precisely where the obstacle lay, and to state explicitly that the fact that increasing expansion leads to increasing losses by cylinder condensation, the losses increasing in a much higher ratio than the gain, is the practical obstruction in our progress toward greater economy.

FIG. 1.

No. 3 Gray Pig Iron. × 50 Diameters.

FIG. 2.



White Pig Iron. × 20 Diameters.

Fig. 3.

Longitudinal Section of Rolled Bar Iron. × 45 Diameters.

Fig. 4.

Cross-Section of Rolled Bar Iron. × 45 Diameters.

"Clark, after a long and arduous series of trials of locomotive engines, and prolonged experiment looking to the measurement of the magnitude of the waste produced as above described, concludes: 'The magnitude of the loss is so great as to defeat all such attempts at economy of fuel and steam by expansive working, and it affords a sufficient explanation of the fact, in engineering practice, that expansive working has been found to be expensive working, and that, in many cases, an absolutely greater quantity of fuel has been consumed in extended expansion working, while less power has been developed.' He states that high speed reduces the effect of this cause of loss, and indicates other methods of checking it. He states that 'the less the period of admission relative to the whole stroke, the greater the quantity of free water existing in the cylinder.' His experiments, revealing these facts, were, in some cases, made prior to 1852. But the men handling the engines had observed this effect even before Clark; he states that they rarely voluntarily adopted 'a suppression of above thirty per cent.,' as they found the loss by condensation greater than the gain by expansion. Describing the method of this loss, this author goes on to say that 'to prevent entirely the condensation of steam worked expansively, the cylinder must not only be simply protected by the non-conductor—it must be maintained by independent external means, at the initial temperature of the steam.' He thus reiterates the principle expressed by Watt three-quarters of a century before, and applies it to the newly-stated case.

"The same author, writing in 1877, says: 'The only obstacle to the working of steam advantageously to a high degree of expansion in one cylinder, in general practice, is the condensation to which it is subjected, when it is admitted into the cylinder at the beginning of the stroke, by the less hot air surfaces of the cylinder and piston, the proportion of which is increased so that the economy of steam by expansive working ceases to increase when the period of admission is reduced down to a certain fraction of the stroke, and that, on the contrary, the efficiency of the steam is diminished as the period of admission is reduced below that fraction.' The magnitude of this influence may be understood from the fact that the distinguished engineer, Loftus Perkins, using steam of 300 pounds pressure, and attaining the highest economy known up to his time, found his engine to consume 1·62 pounds of

fuel per hour per horse-power; while this figure is now reached by engines using steam at one third that pressure and expanding about the same amount, and sometimes less.

"Mr. Humphreys, writing a little later than Clark, shows the consumption of fuel to increase seriously as the ratio of expansion is increased beyond the very low figure which constituted the limit in marine engines of his time.

"Mr. B. F. Isherwood, a chief engineer in the United States Navy, and later Chief of the Bureau of Steam Engineering, seems to have been the first to attempt to determine, by systematic experiment, the law of variation of the amount of cylinder condensation with variation of the ratio of expansion, in unjacketed cylinders. Experimenting on board the United States Steamship *Michigan*, he found that the consumption of fuel and of steam was greater when the expansion was carried beyond about one-half stroke than when restricted to lower ratios. He determined the quantity of steam used, and the amount condensed, at expansions ranging from full stroke to a cut-off at one-tenth. His results permit the determination of the method of variation, with practically satisfactory accuracy, for the engine upon which the investigation was made, and for others of its class. It was the first of a number of such investigations made by the same hand, and these to-day constitute the principal part of our data in this direction. The writer, studying these results, found that the cylinder condensation varied sensibly as the square root of the ratio of expansion, and this is apparently true for other forms and proportions of engine. The amount of such condensation usually lies between one-tenth and one-fifth the square root of that ratio, if estimated as a fraction of the quantity of steam demanded by a similar engine having a non-conducting cylinder.

"The state of the prevalent opinion on this subject, at the time of this work of Clark and of Isherwood, is well expressed by the distinguished German engineer, Dr. Albans, who, writing about 1840, says of the choice of best ratio of expansion: 'Practical considerations form the best guide, and these are often left entirely out of view by mathematicians. Many theoretical calculations have been made to determine the point, but they appear contradictory and unsatisfactory.' Renwick, in 1848, makes the ratio of initial divided by back pressure the proper ratio of expansion, but

correctly describes the effect of the steam jacket, and suggests that it may have peculiar value in expansive working, and that the steam may receive heat from a cylinder thus kept at the temperature of the 'prime' steam. John Bourne, the earliest of now acknowledged authorities on the management and construction of the steam engine, pointed out, at a very early date, the fact of a restricted economic expansion. Rankine recognized no such restriction as is here under consideration, considered the ratio of expansion at maximum efficiency to be the same as that stated by Carnot and by other early writers, and only perceived its limitation by commercial considerations, a method of limitation of great importance, but often of less practical effect than is the waste by condensation. In his *Life of Elder* (1871), however, he indicates the existence of a limit in practice, and places the figure at that previously given by Isherwood, for unjacketed engines. By this latter date, the subject had become so familiar to engineers that a writer in *London Engineering* in 1874, contemns writers who had neglected to observe this limitation of efficiency as indulging in 'mediæval twaddle.'

"A few writers on thermodynamics finally came to understand the fact that such a limitation of applied theory existed. M. G. A. Hirn, who, better than probably any authority of his time or earlier, combined a knowledge of the scientific principles involved with practical experience and experimental knowledge, in his treatise on thermodynamics (1876), concludes: '*Qu'il est absolument impossible d'édifier* a priori *une théorie de la machine à vapeur d'eau douce d'un charactère scientifique et exact,*' in consequence of the operation of the causes here detailed. While working up his experiments upon the performance of engines, comparing the volume of steam used with that of the cylinder, he had always found a great excess, and had, at first, attributed it to the leakage of steam past the piston; but a suggestion of M. Leloutre set him upon the right track, and he came to the same conclusion as had Watt so many years before. He explains that errors of thirty, or even up to seventy per cent. may arise from the neglect of the consideration of this loss. Combes had perceived the importance of this matter, and De Freminville suggested the now familiar expedient of compression, on the return stroke as nearly as possible to boiler pressure, as a good way to correct the evil. The

matter is now well understood by contemporary writers, and it has become fully agreed, among theoretical writers as well as among practitioners, that the benefit of extended expansion in real engines can only be approximated to that predicted by the theory of the ideal engine, by special arrangement having for their object the reduction of cylinder waste, such as superheating, 'steam jacketing' and 'compounding.'

"Professor Cotterill has given more attention to this subject than any writer up to the present time. He devotes a considerable amount of space to the study of the method of absorption and surrender of heat by the metal surfaces enclosing the steam, constructs diagrams which beautifully illustrate this action, and solves the problems studied by him with equal precision and elegance of method. He summarizes the experimental work done to the date of writing, and very fully and clearly exhibits the mode of transfer of heat past the piston without transformation into work. Professor Cotterill's treatise on the steam, 'considered as a heat engine,' is invaluable to the engineer.

"Thus the theory of the steam engine stands to-day incomplete, but on the verge of completion, needing only a little well-directed experimental work to supply the doubtful elements. Even these are becoming determined. Isherwood gives facts showing waste to be proportional, very nearly, if not exactly, to the square root of the ratio of expansion, and Escher, of Zurich, has shown the loss to be also nearly proportional to the square root of the time of exposure, or, in other words, to the reciprocal of the square root of the speed of rotation, and it only remains to determine the method of variation of loss with variation of range of temperature to give the whole of the necessary material for the construction of a working theory which will enable the engineer to estimate, in advance of construction, the economic performance of his machine. There will undoubtedly be much more to be done in constructing an exact theory involving all the physical changes occurring in the working of the heat engines familiar to us; but it will yet be done, and probably very soon. It is the hope of the writer that experiments made under his direction recently may furnish the needed data, as the result of the first systematic research directed to that end; but if this should prove not to be the fact, it cannot be long before direct investigation will secure all essential knowledge.

When this is the case, the remarks of those distinguished physicists and engineers Hallauer and his great teacher Hirn will be no longer well based upon apparent fact.

"Says Hirn, in his memorable discussion with Zeuner, in regard to this subject: '*Ma conviction reste aujourd'hui ce qu'elle était il y a vingt ans, une théorie proprement dite de la machine à vapeur est impossible; la théorie expérimentale, établie sur le moteur lui-même et dans toutes les formes où il a été essayé en mécanique appliquée peut seule conduire à des résultats rigoureux.*'

"Chronologically considered, it is seen that the history of the growth of the theory of the steam engine divides itself distinctly into three periods, the first extending up to the middle of the present century, and mainly distinguished by the attempts of Carnot and of Clapeyron to formulate a physical theory of the thermodynamics of the machine; the second beginning with the date of the work of Rankine and Clausius, who constructed a correct thermodynamic theory; and the third beginning a generation later, and marked by the introduction, into the general theory, of the physics of the conduction and transfer of that heat which play no part in the useful transformation of energy. The first period may be said to include, also, the inauguration of experimental investigation, and the discovery of the nature and extent of avoidable wastes, and attempts at their amelioration by James Watt and by John Smeaton. The second period is marked by the attempt, on the part of a number of engineers, to determine the method and magnitude of these wastes by more thorough and systematic investigation, and the exact enunciation of the law governing the necessary rejection of heat, as revealed by the science of thermodynamics. The third period is opening with promise of a complete, and practically applicable, investigation of all the methods of loss of energy in the engine, and of the determination, by both theoretical and experimental research, of all the data needed for the construction of a working theory.

"The writer would therefore make the classification of these successive stages in the progress here described, thus:—

"(1.) Primary period.—That of incomplete investigation, and of earliest systematic, but inaccurate, theory.

"(2.) Secondary period.—That of the establishment of a correct thermodynamic theory, the *theory of the ideal engine.*

"(3.) Tertiary period.—That of the production of the complete theory of the engine, of the true *theory of the real engine.*"

4. PROPER METHOD OF INVESTIGATION—CONDITIONS DEFINED.

The deficiency of complete data on the subject in hand has already been alluded to. The most complete are those embodied in the report of Chief Engineer B. F. Isherwood, U. S. Navy, of the trials made by a board of Naval Engineers, on Marine Engines.*

These trials were made particularly to ascertain the effect of varying ratio of expansion upon cylinder condensation; for this reason and from the type of the engines on which they were made, the data are very incomplete and unsatisfactory.

To determine by experiment the part which each of the factors, ratio of expansion, pressure and piston speed plays in causing the great loss of heat found to occur in the engine cylinder, due to condensation, by noting the effect produced by variation in all of them at the same time, or in other words, to make a series of trials, beginning with a known value for ratio of expansion, pressure and piston speed within the power of the engine and boilers to maintain and keep them constant throughout one trial of any desired length, and then for the next trial give different values to each of these three quantities, and likewise for each succeeding trial, and, from the data obtained, deduce the law governing each case, would be extremely difficult, if not absolutely impossible.

After much thought on the plan to pursue, the writers decided that determining the effect of each factor separately, and afterwards, if possible, combining the results obtained into one expression representing the effect which would be produced by giving different values to one or all of the three variables which would of necessity enter into the equation, would without doubt be the simplest and best plan and at the same time bring success within a probability.

* Engineering Researches.

## CHAPTER II.

### 5. MACHINERY AND APPARATUS.

The engine used in our experiments is located at the Upper Rubber Mill, of the New York Belting and Packing Company, Sandy Hook, Conn.

It was built by Wm. A. Harris, Providence, R. I , in 1880, and is of the type known as the Harris-Corliss engine.

It is 42-inch stroke of piston, 18-inch diameter of cylinder, and is fitted with the ordinary jet condenser and reciprocating air-pump, 9-inch diameter of cylinder by 10-inch stroke; but, as will be seen from the logs of trials, the condenser can be disconnected and the engine worked without condensation.

The injection water was obtained from the head-race, leading from the mill dam to the water-wheel, and entered the condenser on an average temperature of about 68° Fahrenheit. The valve gear consists of a wrist-plate, operated by the eccentric, and to which are connected four rods, operating all the valves, the two steam valves being closed by vacuum dash pots.

The steam valves are tripped at the proper moment by small cams on the stem of each valve, which are operated by the governor, thus securing the automatic cut-off, which is a recognized essential.

The exhaust of engine is closely connected to the condenser by a seven-inch pipe, and steam is conveyed from the boilers by a five-inch pipe, well protected with hair felt and canvas. The cylinder was not jacketed, but was covered with a non-conducting substance and wooden staves. The engine is furnished with a pulley fly-wheel, 14 feet in diameter and 25-inch face, belted to a jack-shaft, which in turn is coupled to the main shaft of the mill; but in these trials this coupling was removed and the work supplied by a brake, which will be described later on. When in actual use, the engine is run about four months out of the twelve, water-power being sufficient for the remainder, its work consisting in giving motion to grinders and sheeters, ordinarily used in the preparation of rubber prior to its vulcanization into the various forms in which it is commercially used. It was found upon a preliminary examination to be in excellent condition, steam and exhaust valves were tight and, in fact, the seats showed no wear whatever.

Leakage of the piston was particularly looked for, since in these trials particularly, its existence would be fatal; but it was found to be absolutely tight.

### 6. THE BOILERS.

Steam was furnished in most of the trials by two boilers, but in two instances it was found necessary to use a third. They were built at the Bridgeport Boiler Works, Bridgeport, Conn., in 1880, and are a standard type of the horizontal fire tube boiler, the only notable peculiarity about them being that the gases from the furnace are prevented from directly circulating toward the back and by a bridge wall built of fire brick; but instead are carried upwards through two large holes in the forward end of the crown sheet, to the combustion chamber, which really corresponds to the furnace of an upright boiler.

There they are drawn through the tubes, deflected downwards underneath the back part of the boiler, and then up the chimney, passing through a feed-water heater in their escape.

The principal dimensions are as follows:

| | |
|---|---|
| Diameter of shells, . . . . . . . . . . . . | 42 inches. |
| Length, . . . . . . . . . . . . . . . . . . | 17 feet 6 " |
| Number of tubes, each boiler, . . . . . . . | 37 |
| Diameter of tubes, . . . . . . . . . . . . | 3 " |
| Length of tubes, . . . . . . . . . . . . . | 14 feet. |
| Heating surface, each shell, . . . . . . . . | 192·5 square feet. |
| Heating surface of tubes, each boiler, . . . . | 407·0 " " |
| Heating surface of heads, each boiler, . . . . | 19·2 " " |
| Total heating surface, . . . . . . . . . . . | 618·7 " " |

### 7. SPECIAL APPARATUS.

*Brake.*—As we believe this is the largest brake of its kind ever constructed, the design is given in detail and described separately.

*Indicators.*—The indicators used were "Thompson," two in number, Nos. 549 and 340, manufactured by the American Steam Gauge Company, and, tested by them after the trials were completed, the springs were found to be correct, the pistons tight, and the indicators to be in good order. The motion was obtained indirectly from the cross-head of the engine, through a strip of wood oscillating about a pin and fastened in the ceiling of the engine room and linked to a three-quarter-inch iron rod fastened rigidly

to the cross head. The line was fastened to the stick at a point sufficiently far from the centre of oscillation to give the required length of card, and which length remained sensibly constant during the trials.

In running under variable pressures, the spring was changed for each trial, so as to give a sufficient height of card to readily admit of measurement; but when the pressures were constant through a whole set the same spring was used.

*The Weir*—The writers thought it advisable, as a means of check, to ascertain the number of heat units carried off by the condensing water. To compute this, we must first know the weight of water discharged from the condenser, and, secondly, its rise in temperature. The most correct method for getting this necessary data, was by the use of a tumbling bay or weir, through which all the condensing water is made to pass, a method as yet in very little use in this country, but more familiar in Great Britain.

The appliances required are very simple, and can be readily fitted to any engine. It consisted of a strong water tight wooden box, 5 feet long, 2 feet 6 inches deep, and 2 feet wide.

It is fitted near one end with a series of perforated transverse partitions, while at the other end an aperture 8 x 10 inches is cut out, forming a notch, there being fixed outside of the notch a thin brass plate ⅛ inch thick, having an opening in it corresponding with that in the box, but somewhat smaller (6 x 8 inches) and having its edge bevelled outwards, so that the water flowing through encounters very little resistance from friction. One foot and a half back from this notch, and across the top of the box, is fastened a strip of wood 2½ x 3 inches, to which is bolted a micrometer screw, made with the greatest nicety and capable of being read to the $\frac{1}{10000}$th part of an inch, on the end of this is fastened a hook gauge, such as is commonly used in measuring the flow of water, its *o* being on a level with the horizontal edge of the notch.

The whole apparatus was placed in a level position under the end of the discharge pipe from the condenser, so that the issuing water would have a clear fall of 14 inches. The water entering the box passed through, over and under the transverse partitions, being thus thoroughly mixed in its course, and at the same time

sending it quietly and smoothly under the hook gauge, where its head above the bottom of the notch was measured.

*The Meter.*—A two-inch Worthington Meter was introduced in the feed pipe leading from the feed water heater, so that the weight of water passing into the boilers could be easily calculated, the height in the glass gauges was noted at the beginning of the trial, and at the end it was made to exactly agree, so that the meter readings in cubic feet reduced to pounds would exactly represent, after deducting that which passed through the calorimeter, the amount of water evaporated by the boilers and sent over to the engine, in the form of steam. Between the boilers and the meter, and close to the latter was fitted a drip pipe, furnished with a stop-cock, so that the temperature of the feed water could be read at pleasure.

*The Calorimeter.*—A one-inch pipe lead from the steam dome of one of the boilers (and indirectly from the other, as both boilers were of course connected) to a calorimeter. This was obtained from the Stevens Institute of Technology, and is the one used there in all their boiler trials. It consists of a wooden tank, lined inside with zinc and packed with hair felt to prevent radiation, the tank being capable of holding 100 pounds of water. Inside is a coil of ½-inch pipe connecting with the pipe leading from the boiler by a three-way cock, so that the steam can be passed through it, or into the air when desired.

At each test, a known weight of water is introduced into the tank surrounding the coil and being thoroughly mixed by means of a float which can be moved through the liquid. By this simple apparatus, the percentage of water passing over with the steam to the engine is easily determined, and the method of calculating it from the data obtained from observation will be found in Chapter IV.

8. METHOD OF STANDARDIZING THE SPECIAL APPARATUS AND RESULTS.

The vacuum and steam gauges used in the trials were manufactured by the American Steam Gauge Company, and the latter was carefully standardized by us before and after the trials by comparison with one of Shaw's Mercurial Pressure Gauge, and found to exactly correspond with it at all pressures between the limits at which we worked, these being the only ones at which we subjected it to the comparison.

(*To be Continued.*)

# THREE NEW PORTRAITS OF WASHINGTON.*

## COMPOSITE PHOTOGRAPHY.

The FRANKLIN INSTITUTE has so recently done me the honor to invite an exhibition and description of composite photography, and the proceedings on the occasion were so fully reported in the August number of the JOURNAL, that no extended description of the plate here published may now be required. These Washington portraits (marked "*Composite*" on the plate), made by combining the various representations that have come down to us, ought to have a peculiar historical value, in that they are, each, the sifting of the testimony of a number of eye-witnesses. In the case of the upper composite—the profile—seven artists, whose names are attached to the surrounding originals, present, as a body, their impressions of the great man's appearance; and, as each artist has only one-seventh of a showing in the result, no unsupported individual notion can possibly assert itself. The same may be said of the two other composites at the bottom of the plate, except that each of these combines five originals.

The most complete demonstration of the value of this method of photography lies in the fact that, while the conceptions of the individual artists are so diverse, the combined testimony of the several groups is to one effect; for the composite of the seven and each composite of five look like one man, which cannot be said of the individual heads.

So much admiration has been expressed about the beauty of the composite on the lower right of the plate that we are having it finished finely, of life size, in crayon, for exhibition at the "NOVELTIES." Care will be taken not to disturb the peculiar sketchy look of the composite, and to change none of the suggestions of its multifarious origin, nor any characteristics which, by their prominence indicate a weight of authority for their retention. If this purpose be carried out with the skill we hope for, the result ought to be a Washington with higher credentials than any that has preceded it, for it will have the authority of fourteen contemporaneous

* See Frontispiece.

artists, adjusted to agreement. This portrait or one founded on a similar method will, in time, be esteemed as the truest likeness of the Father of his country.

Every reader, convinced of the reasonableness of what is here said, will recognize that composite photography has before it an important future, in those departments of portraiture to which it is adapted. And it is pleasant to reflect that our FRANKLIN INSTITUTE has been so prompt to illustrate its claims before the public.

W. CURTIS TAYLOR.

## THE MICROSCOPIC STRUCTURE OF IRON AND STEEL,*

BY F. LYNWOOD GARRISON, Philadelphia, Pa.

[*Read at the Chattanooga meeting of the American Institute of Mining Engineers, May, 1885.*]

It is not intended to make in the present paper any deduction or to formulate any theories from the results obtained by experiments. The further expenditure of considerable time and labor would be required to obtain a sufficient basis for positive assertions as to the microscopic structure of the different varieties of iron and steel, and the structural changes which take place in them. It is therefore my purpose at this time to offer simply a synopsis of the general results arrived at in a few months' work, a brief description of apparatus used, and a few hints as to the preparation and preservation of the material which it is intended to investigate.

The study of the microscopic structure of iron and steel is not altogether new. Some attention has been given it in both England and Germany. But the foreign publications on the subject have thus far been confined, so far as I am aware, to two papers, one by Herr Martens, of Berlin, contributed to the *Verein zur Befoerderung des Gewerbfleisses*, and the other a lecture by Dr. H. C. Sorby, of Sheffield. Dr. Sorby, it seems, was induced to investigate the subject as bearing on the structure of meteoric iron; and the results he obtained are certainly very interesting. At the Boston meeting of this Institute, in February, 1883, Mr. J. C. Bayles called attention to the subject in a neat and exceedingly

*From Advance Sheets of the Transactions of the American Institute of Mining Engineers.

interesting paper, in which the work of Messrs. Martens and Sorby was summarized,† and original suggestions were added.

It is at present difficult to say what will be eventually the practical value of the microscope, thus employed, in the sciences of engineering. The *rôle* which it seems most likely to play is that of an adjunct to the testing-machine, and not (as some have supposed) a rival to the chemical laboratory. That it will be a most valuable accessory seems, to say the least, highly probable.

I need hardly go at length into the details of preparing the material for examination. Mr. Bayles has described the process in such a plain and comprehensive manner, that if his instructions are carefully followed, one need not encounter any serious obstacles after a little experience and the expenditure of a considerable amount of time and patience. Patience and cleanliness are the two most important attributes to be acquired by a student, if he desires success in work of this character. A deficiency in either will be sure to spoil his work, and in the end he will give it up in disgust wondering what has been the cause of his failures.

In grinding the specimens, it is quite unnecessary that they should be ground to an extreme thinness and mounted in Canada balsam as microscopical objects are usually preserved. This entails a vast amount of labor, to no end whatever. A good and accurate photograph, once obtained, is usually sufficient for any reference that might be desired in the future; besides, with a little care the etched surfaces of the objects can be preserved from rust by simply rubbing a few drops of kerosene oil over them with a soft chamois-skin and then placing them in a tightly-corked phial.

The size of the objects to be examined under the microscope, may vary considerably; but the sizes found most convenient range from $\frac{1}{4}$ down to about $\frac{1}{16}$ of an inch in thickness and from an inch to $\frac{1}{5}$ of an inch in sectional area. If the specimens are extremely thin, there is often much difficulty in mounting them properly on a slide, and getting the etched surface perfectly parallel to the object-glass. After the surface has been sufficiently treated with acid, and shows under the microscope no further traces of scratches made in the grinding, it should be carefully dried and cemented to a glass slide with wax or cement, great care being taken to have

† Transactions. vol. xi., p. 261.

it in the proper plane parallel to the object-glass: otherwise, it will be impossible to make a satisfactory photograph.

The greatest difficulty encountered in pursuing the study of the structure of materials is that of making accurate and satisfactory records of what is seen under the microscope. To effect this, the only accurate and quick means is to photograph. Hence the student must not only be a good microscopist, but also understand the theory and practice of photography, an accomplishment which every engineer will find it useful to acquire. The subject of photo-microscopy, although a comparatively new one, is somewhat extensive, and it would not be within the scope of this paper to enter upon it in detail. A few hints, however, may be of value. The camera should not be large; the most convenient size will be found to be one using 4¼ x 5½-inch plates, and having a bellows capable of being extended several feet. Instantaneous dry plates only should be used, for experience has shown that no others will serve the purpose half as well; and they should be developed with a weak solution of an alkaline or a ferrous oxalate developer. It is found that when an instantaneous plate is used, it is better to make a comparatively long exposure and use a weak developer than to make a short exposure and use a strong developer.* The time of exposure depends upon many conditions, such as the clearness of the atmosphere, the intensity with which the etched surface reflects light, the quality of the objectives, and the sensitiveness of the gelatine plate. The above conditions are frequently so complex that it would be impossible to say just how long the exposure should be made; the student must learn to judge this by experience. A safe limit, however, may be placed at not over twenty seconds, when good *direct* sunlight can be obtained and a perfectly instantaneous plate used.

The proper illumination of the object to be photographed under the microscope is somewhat difficult and requires considerable practice to effect it. It must also be borne in mind that the best results can be obtained only by direct sunlight, unobscured by clouds or mists. When the object to be photographed has been carefully adjusted on the stage of the microscope, and the focuss-

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*A developer diluted to *one-half* its usual strength will be found to give excellent results.

ing has been approximately made, the table (holding both the camera and microscope) is placed near the window, so that the sunlight may strike *directly* upon the object. The fine focussing is then made by means of a cord passing around in a groove in the periphery of the fine adjustment-screw of the microscope. The image on the ground glass should be perfectly clear and well-defined in all its details. To effect this, a focussing glass, such as is ordinarily used by photographers, may be used with advantage in adjusting the finer details. The use of a condensing lens depends upon the ability of the etched surface to reflect light. Thus, for instance, hard steel reflects light so well that a condensing lens is necessary, while in the case of pig, cast, or wrought iron, its use is absolutely essential. For further particulars on this subject, Dr. Sternberg's work, *Photo-Micrographs and How to Make Them*, is recommended.

In selecting a microscope, though the question of cost is of primary importance to many, it should be remembered that a good instrument once obtained will, with proper care, last a life-time. Such an instrument, under ordinary circumstances, should not cost less than $35 or $40, although a good second-hand one may be obtained for less. The most important points to be observed in selecting a microscope, with which it is intended to take photo-micrographs, are as follows:

(1.) The stand should be of the best workmanship and material; there should be no "shake" or lateral motion; in the adjustment of the focus, there should be no "lost motion"—that is, the focus should instantly change with the slightest motion of the milled heads—and for photography there *must* be a universal joint, for inclination.

(2.) The instrument must be provided with a fine adjustment-screw with a groove turned in its periphery.

(3.) The mirror under the stage should be so constructed that it can be made to swing over, around, and above the stage, thus affording a means of more intense illumination to the object than otherwise could be obtained with opaque substances. The objectives should be of the very best quality. Experience has shown that it is poor economy to use any others. Beck's ⅔-inch and 1½-inch will be found to give excellent results, and a range of powers quite sufficient for any ordinary work. There are a number of

makers of objectives, all about equally good, but as I have used Beck's lenses only, I say nothing about the rest. Two great points to be observed in selecting an objective are, that it has a good "*penetration*" and an extra lens (to be used only when photographing), so that the visual and chemical foci may be made to coincide. The correction of Beck's is effected in the 1⅔-inch by substituting for the back-stop a double convex lens of 8-inch focus. and for the ⅔-inch a double convex lens of 5-inch focus. Higher powers need no correction, and lower ones than 1½ inch are rarely employed.

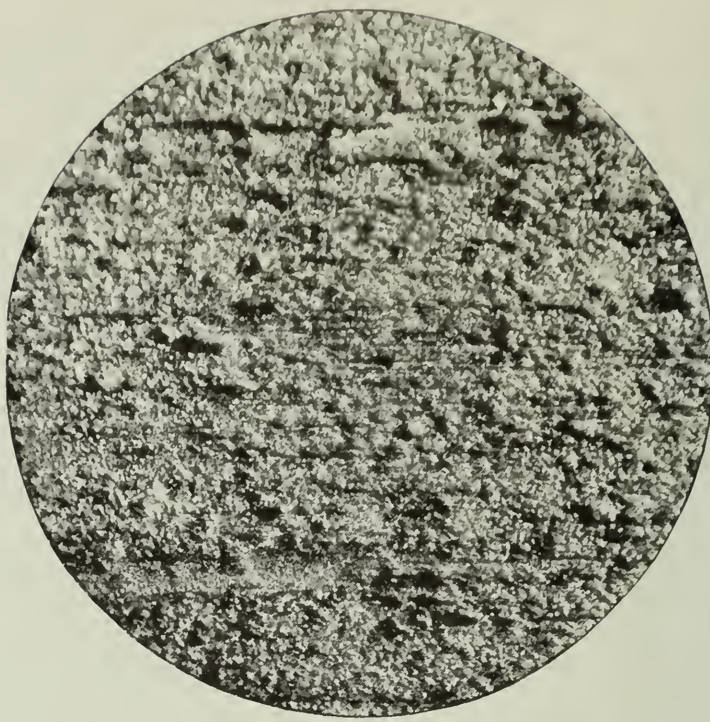
The quality of the eye-piece is of secondary importance, as it is never used in photographing. The attachment of a mechanical stage to the microscope is a great convenience and economizer of both time and patience, although it is not an absolute necessity. Dr. Carpenter's work and Dr. Phin's *Hints on the Selection and Use of the Microscope*, together with Dr. Sternberg's work are recommended to those who may desire further details on the several subjects.

Of all the varieties of iron and steel, pig and cast iron are the most difficult to prepare for examination.

*Fig. 1* represents a No. 3 pig iron (gray) as it appears under a power of fifty diameters. The specimen was prepared and etched with the greatest possible care, so that it may be safely taken as a good example of pig iron, ranging from No. 1 to No. 4, when magnified to that degree. It will be seen to consist of a heterogeneous mixture of metallic iron and long, narrow, black plates of graphite. It does not appear to bear the slightest trace of any crystalline structure. The straight black lines which seem to stand out in relief are the graphite plates. Owing to the comparatively high power used in this case, the slightest inequalities of the etched surface cause an unevenness in the focussing; hence the obscurity of some parts of the plate. By close observation of some parts, however, the structure and the graphite plates can be made out. In many cases of pig and cast iron the graphite plates seem to group themselves in bunches or lumps. This seems to be more characteristic of cast than of crude pig iron. It is not unlikely that the second melting and slow cooling enables the graphitic carbon to separate itself more readily in that way.

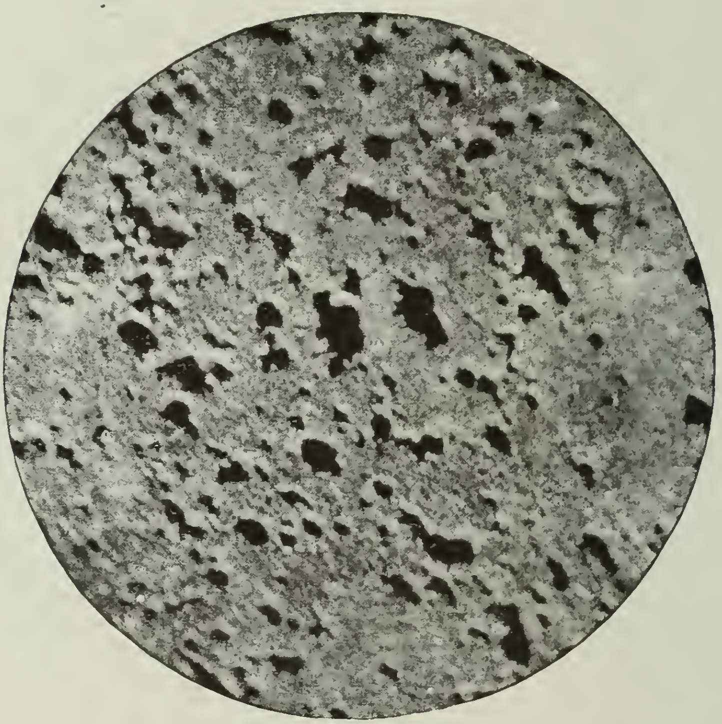
White pig iron exhibits a highly crystalline structure, as will

FIG. 5.



Longitudinal Section of a Bolt of Clapp-Griffiths Steel. $\times$ 45 Diameters.

FIG. 6.



Cross-Section of a Bolt of Clapp-Griffiths Steel. $\times$ 45 Diameters.

FIG. 7.

Crucible Tool Steel. × 45 Diameters.

FIG. 8.

File Steel. × 40 Diameters.

be seen in *Fig. 2*. The intensity of the crystallization depends very much upon the degree of chilling. Thus, in a large casting made in a metallic mould, the outer surface, which comes in contact with the mould, will be found to exhibit a high crystalline structure (such as shown in *Fig. 2*), while the inner part, which has cooled slowly, will show very little, or, perhaps, no crystalline structure. This highly crystallized white iron exhibits, even under a high power, only a comparatively small number of graphitic plates. The crystalline structure in some cases is irregular, while in others the crystals are regularly arranged, with their long axes normal to the surface of the mould. The plates of graphite will be found to be arranged parallel to the lines of crystallization.

Wrought iron or mild steel exhibits a fibrous structure, running in the direction in which it has been rolled. *Fig. 3* shows the structure of a fine quality of rolled bar iron. The fibre is distinct, and shows numerous furrows and cavities, due to working, and the presence of intermingled slag during the rolling. Wrought iron (not steel) does not show, even under a power of 100 diameters, the slightest trace of crystalline structure. It has been held by Percy and other authorities that the fibres were simply drawn out crystals. I have tried, in numerous instances, to determine if such really was the case, and, although I have examined many longitudinal and cross-sections of various grades, I cannot find that there exists any foundation for such a view.

*Fig. 4* shows a cross-section of the same material as *Fig. 3*. The furrows of *Fig. 3* will be seen to be replaced by irregular cavities in the cross-section.

*Figs. 5* and *6* show, respectively, a longitudinal and a cross-section of a bolt made of Clapp–Griffiths steel. The difference in structure between iron and steel can be readily seen in this case, the latter showing a fibrous and yet finely granular structure, characteristic of steel.

Hard, or tool steel, presents a structure entirely different from any of the preceding. It is highly crystalline, uniform in structure, and shows no lines of weakness, or any tendency in the crystals to develop themselves in any given direction. *Fig. 7* is a high-grade crucible tool steel magnified forty-five diameters.

*Fig. 8* is the usual grade of file steel magnified to the same

degree. The latter differs from crucible tool steel only in being somewhat more compact and harder. All steels exhibit a similar characteristic structure, which enables a person, with practice, to judge of their relative qualities by a simple comparison of their compactness, lustre and crystalline structure.

*Fig. 9* shows the structure of meteoric iron, which is quite different from any of the artificial irons, or alloys of iron and nickel. The peculiar lines so prominent in the figures are characteristic of meteoric iron, and are commonly known as "Widmannstatten lines." I have not been able to detect these lines in all varieties of meteoric iron. It seems that if the iron be very impure, and contain but a small amount of nickel, there is little or no tendency to develop them.

One of the most interesting and peculiar changes of iron into steel, which have come under my notice in connection with this subject, is exhibited in *Fig. 10*. It shows a section made from a "burnt-out" grate bar of ordinary cast iron. The left hand side (*A*) shows the cast iron unaltered by the action of the heat; the right side shows where the cast iron has been completely changed to hard steel, which resists the file quite as much as any tool steel. On examination of the part of the bar which came most in contact with the fire, I found that the entire surface was changed to hard, compact steel, with a thickness of about one-tenth of an inch. The most remarkable point, to my mind, is that the line of demarcation is so sharply defined, thus showing little or no intermediate stage of decarbonization. The altered part (*B*) shows a structure decidedly characteristic of hard tool steel (compare with *Fig. 8*). In the unalterable part (*A*), the structure of cast iron is quite apparent, the groups and clusters of graphite plates being readily distinguishable (compare with *Fig. 1*). As the reasons for such a remarkable change of structure might cause considerable speculation and much difference of opinion, it would, perhaps, be better to defer its discussion for another opportunity and a separate paper.

In conclusion, it is most earnestly desired that this paper may excite a friendly criticism and discussion of the subject, by which we may learn the opinions and experiences which others have had of the physical properties of iron and steel. From any persons interested, I should be very glad to receive such specimens or information as they may see fit to send.

# BOOK NOTICES.

Chemical Problems. By Dr. Karl Stammer. Translated from Second German Edition, by W. S. Hoskinson, A. M. P. Blakeston, Son & Co. 1885.

This little work, of about a hundred pages, is published without a preface. It is, however, evidently intended to be a guide to the teacher, rather than to the student, since all the problems have their respective answers given in the end of the book, and, moreover, there is very little explanatory comment in any part of the work, such as a learner in the science would require.

The problems are essentially stoichiometrical questions, and relate to all of the commonly occurring elements—each element having several pages of questions, which are varied in every conceivable manner.

Indeed, the book, so far as it goes, is quite exhaustive, and is a good example of German thoroughness in compilation.

There are two objections to the work; a large portion of the questions are exactly such as arise in the practice of analytical chemistry, and have to be solved daily in both gravimetric and volumetric work. It is quite certain that a much deeper impression would be made upon the student who attacks such questions one by one as they occur in laboratory work, than would be made by attempting to figure through Dr. Stammer's several thousand "problems." Such an effort would prove a weariness to the flesh, and would probably exhaust all enthusiasm the student might feel for the science.

Secondly, there is rather a superabundance of material offered. A few pages, for instance, would be quite sufficient to thoroughly explain the metric system; yet, all through the work, answers are required in grams, pounds, kilograms, etc. This is a waste alike of the printer's ink and of the reader's patience.

A few errors are noticeable; chromite is spoken of (page 74) as though it were a pure spinel type, containing only one atom of ferrous and of chromic oxides, with no other bases present. Such a chromite does not exist. Again, the atomic weight of aluminum is stated to be 27·4; Mallet has shown that its correct weight is 27. The book is clearly printed, and appears to be well translated. Problem 42, page 71, being an exception in this latter respect.

H. P., Jr.

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Theorie Elastischer Körper. Eine Einleitung zur Mathematischen Physik and Technischen Mechanik. Von Dr. Jacob J. Weyrauch. Leipzig. 1884. And

Aufgaben zur Theorie Elastischer Körper. Von Dr. Jacob J. Weyrauch, Leipzig. Druck und Verlag von B. G. Teubner. 1885.

The want of a comprehensive theory, which should include all phenomena due to the elastic properties of solid, fluid and gaseous bodies, has induced the author to develop a general theory, and he has accomplished this task as only a man can do who fully abandons himself to it, only striving to fathom the subject to the bottom, no matter whether the benefit of his labors will accrue to himself or to others.

He found it necessary to introduce new concepts and new functions. After first developing the most general laws, he deduces from them the laws bearing on special cases and special phenomena. The deductions are throughout analytical, and since the nature of the subject demanded the triaxial system, the formulæ appear mostly in triplets.

All bodies are supposed to consist of material elements which exert upon each other pressures, that as a rule, are not at right angles to the contact surfaces. These forces are resolved in right-angular tensions and parallel shifting forces, and, by examining their tendencies in their entirety, the respective mathematical formulæ are deduced. As these forces produce motion, the theory of vibration is established.

In the *Aufgaben* the application is shown of the fundamental formulæ, to the solution of general problems bearing on the subject of elastic bodies.

H. B.

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Das Princip von der Erhaltung der Energie seit Robert Mayer. Zur Orientirung. Von Dr. Jacob Weyrauch. Leipzig, Druck und Verlag von B. G. Teubner. 1885.

This is a concise treatise on the conservation of the energy of forces with special reference to the time and authorship of the succeeding discoveries, and the general progress of this science, and especially to the literature on the subject. It is therefore a desirable hand-book for those who not only wish to become fully acquainted with the details, but also with the history of this principle which, according to Herbert Spencer, is one of the three great discoveries of this century. H. B.

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The Philadelphia Insurance Chart, for 1885, has been issued by J. H. C. Whiting. It contains a large amount of condensed information, being not only a perfect directory as to insurance companies, agents and brokers, but all the places of interest in the city are given, with information respecting them, the names of streets, their length, width, etc. "How Philadelphia Burns" is shown in a table, evidently made with much care and labor, giving the number of all the vast manufacturing establishments of the city, value of such property attacked by fire, the losses, insurance and ratios, not only for 1884, but for the period of 1874–1884, inclusive. This has now become a standard insurance annual, and will be found also valuable to the statistician and historian. To be obtained from the Review Publishing and Printing Company, Northwest corner Fourth and Walnut Streets. N.

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The Fireman's Guide. A Hand-Book on the Care of Boilers. By Technologföreningen T. I. Stockholm. Translated from the Third Edition and Revised by Karl P. Dahlstrom, M. E. 12 mo. Published by E. & F. N. Spon. London and New York.

This practical book of only twenty-eight pages, including preface, besides being of most respectable technical origin, is conspicuous by extreme conciseness and clearness in statements and recommendations. Such brevity is valuable here, because engineers and firemen will not read extensive treatises.

The chapters comprehend firing and economy of fuel, feeding, low water, pressure, cleaning and blowing out; also, general directions for repairs, prevention of accident, etc. A summary of rules at the conclusion is plain and easy to be remembered. This compact hand-book of boiler management should be owned by every manufacturer or user of steam boilers; and such persons would advance self-interest by presenting a copy thereof to their engineers and firemen. N.

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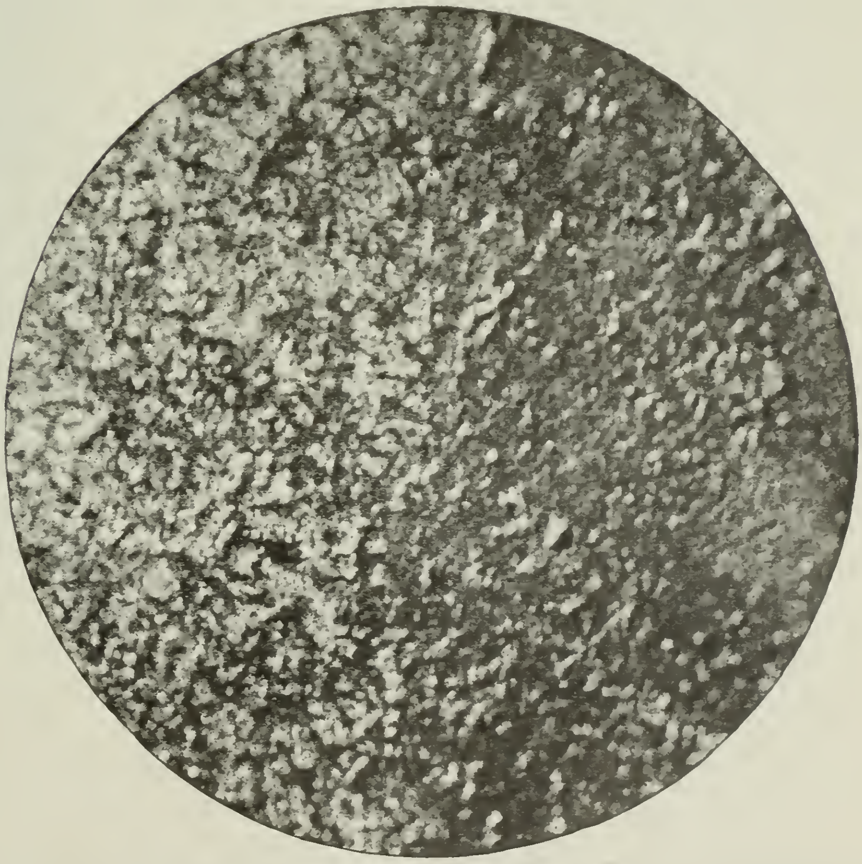
FIG. 9.

Meteoric Iron. × 20 Diameters.

FIG. 10.




"Burnt Out" Grate Bar of Cast Iron. (*A*) The Cast Iron Unaltered by the action of the Fire. (*B*) The Cast Iron Changed into Hard *Steel* by the action of the Fire. × 45 Diameters.

# JOURNAL

OF THE

# FRANKLIN INSTITUTE

OF THE STATE OF PENNSYLVANIA,

FOR THE PROMOTION OF THE MECHANIC ARTS.

VOL. CXX. NOVEMBER, 1885. No. 5.



## ON TIDAL THEORY AND TIDAL PREDICTIONS.

BY E. A. GIESELER,
Superintendent of Construction, Fourth Light-House District.

[*Concluded from Volume CXX., page 252.*]

Having in the above discussed the method of predicting the time of high and low water, we now proceed to the predictions of height.

As mentioned before, the zenith distance of the heavenly bodies from high and low water, at the time of the generating lunar transit, is introduced into the computations of height, in the place of their declination and rectascension (relative meridional position). For this purpose the following tables have been constructed:

*Table 22.*—Zenith Distances of Moon at the Time of the Generating Lunar Transit, from High Water on Parallel 40° North.

| | Lunar Declination. | Zenith distance during Upper Transit of Moon. | Zenith distance during Lower Transit of Moon. |
|---|---|---|---|
| Moon's declination, North. | 30° | 10° | 70° |
| | 20° | 20° | 60° |
| | 10° | 30° | 50° |
| Moon in Equator. | 0° | 40° | 40° |
| Moon's declination, South. | 10° | 50° | 30° |
| | 20° | 60° | 20° |
| | 30° | 70° | 10° |

The differences of the Moon's zenith distance in her various hours of transit are so small that they have been neglected in this table entirely.

*Table 23.*—Zenith Distance of Moon at the Time of the Generating Lunar Transit, from Low Water on Parallel 40° North.

| Lunar Declination, North. | Zenith Distance During: Upper Lunar Transit. (Second Lunar Group.) | Zenith Distance During: Lower Lunar Transit. (First Lunar Group.) | Lunar Declination, South. | Zenith Distance During: Upper Lunar Transit. (First Lunar Group.) | Zenith Distance During: Lower Lunar Transit. (Second Lunar Group.) |
|---|---|---|---|---|---|
| 30° | 78½° | 75° | 30° | 75° | 78½° |
| 25° | 81° | 77° | 25° | 77° | 81° |
| 20° | 83° | 79° | 20° | 79° | 83° |
| 15° | 85½° | 81° | 15° | 81° | 85½° |
| 10° | 87½° | 83½° | 10° | 83½° | 87½° |
| 5° | 90° | 86° | 5° | 86° | 90° |
| 0° | 88° | 88° | 0° | 88° | 88° |

*Table 24.*—Zenith Distances of Sun at the Time of the Generating Lunar Transit, from High Water on Parallel 40° North, for every hour of Lunar Transit and every 10° of Solar Declination.

| Hour of Moon's Transit. | Zenith Distances of Sun when he Declines NORTH. | | | | SOUTH. | | |
|---|---|---|---|---|---|---|---|
| | 23½° | 20° | 10° | 0° | 10° | 20° | 23½° |
| | degrees. | degrees. | degrees. | degrees. | degrees. | degrees. | degrees. |
| 1 | 17½ | 21 | 31 | 41 | 51 | 60½ | 64 |
| 2 | 23½ | 26½ | 35 | 44 | 53 | 63 | 66½ |
| 3 | 31½ | 34 | 41½ | 49½ | 58 | 67 | 70 |
| 4 | 41 | 43 | 50 | 57 | 65 | 73 | 76 |
| 5 | 53 | 55 | 61½ | 68 | 75 | 82½ | 85 |
| 6 | 66 | 68 | 74½ | 81 | 87 | *86* | *83½* |
| 7 | 79½ | 81½ | 88 | *85½* | *79* | *73* | *70½* |
| 8 | *88* | *85½* | *78* | *71½* | *65* | *58½* | *56½* |
| 9 | *77½* | *75* | *67* | *59* | *52* | *45* | *43* |
| 10 | *70* | *66½* | *57½* | *49* | *41* | *33* | *30* |
| 11 | *65* | *62* | *52½* | *42½* | *33½* | *24* | *20½* |
| 12 | *64* | *60½* | *50½* | *40½* | *30½* | *20½* | *17* |
| 13 | *64* | *60½* | *51* | *41* | *31* | *21* | *17½* |
| 14 | *66½* | *63* | *53* | *44* | *35* | *26½* | *23½* |
| 15 | *70* | *67* | *58* | *49½* | *41½* | *34* | *31½* |
| 16 | *76* | *73* | *65* | *57* | *50* | *43* | *41* |
| 17 | *85* | *82½* | *75* | *68* | *61½* | *55* | *53* |
| 18 | 83½ | 86 | *87* | *81* | *74½* | *68* | *66* |
| 19 | 70½ | 73 | 79 | 85½ | 88 | 81½ | 79½ |
| 20 | 56½ | 58½ | 65 | 71½ | 78 | 85½ | 88 |
| 21 | 43 | 45 | 52 | 59 | 67 | 75 | 77½ |
| 22 | 30 | 33 | 41 | 49 | 57½ | 66½ | 70 |
| 23 | 20½ | 24 | 33½ | 42½ | 52½ | 62 | 65 |
| 24 | 17 | 20½ | 30½ | 40½ | 50½ | 60½ | 64 |

NOTE.—The italicized figures in this table refer to lower, the non-italicized to upper transit of Sun.

(*See Table 25.*)

It may be mentioned here as a matter of general interest that the zenith distances of the Sun from high water stand in this relation to the zenith distances of the Moon from high water, that on the annual average the greater zenith distances of one heavenly body are always accompanied by the greater zenith distances of the other, and the smaller zenith distances of one are always accompanied by

the smaller zenith distances of the other in creating tides, all of which is set forth by the following table:

*Table 20.*—Showing the Relation between Mean Solar Zenith Distance and Mean Lunar Zenith Distance from High Water on Latitude 40° North.

| To a Mean Annual Lunar Zenith Distance from High Water of— | Pertains a Mean Annual Solar Zenith Distance from High Water of— |
|---|---|
| degrees. | degrees. |
| 15 | 43 |
| 25 | 46 |
| 35 | 53 |
| 45 | 62½ |
| 55 | 67½ |
| 65 | 70 |

It will be noted that the above tables all refer to latitude 40° North, the writer's original intention having been to utilize tidal observations made at Philadelphia for the practical part of his paper. This intention was abandoned after the tables had been constructed, and it was not considered necessary, for the sake of the small difference in latitude, to go through the laborious process of reconstructing them.

The equatorial positions being the mean positions of the heavenly bodies, we derive their mean zenith distances by taking the mean of the various zenith distances during such equatorial positions, from Tables 22, 23, 24 and 25, as follows:

*Mean Zenith Distances of the Heavenly Bodies on Latitude 40° North, from High and Low Water at the Time of the Generating Lunar Transit.*

$$\left.\begin{array}{ll}\text{(1.) Mean Zenith distance of Moon from High Water,} & 40^\circ \\ \text{(2.) Mean Zenith distance of Moon from Low Water,} & 83^\circ \\ \text{(3.) Mean Zenith distance of Sun from High Water,} & 57^\circ \\ \text{(4.) Mean Zenith distance of Sun from Low Water,} & 62^\circ\end{array}\right\}\ \text{Approximately.}$$

These mean zenith distances correspond to the mean heights of high and low water on latitude 40° North, and a period of nineteen years observed continuously on such latitude would render such means of zenith distances; if, however, as is the case here, a shorter and not continuous period only is available, then the mean sidereal conditions of such shorter and not continuous period may be different, and the means of high and low water obtained from it will

*Table 25.*—Zenith Distances of Sun at the Time of the generating Lunar Transit, from Low Water on Parallel 40° North, for every Hour of Lunar Transit, every 10 Degrees of Solar Declination and every 30 Degrees of Lunar Declination.

| Hour of Moon's Transit. | Zenith Distances of Sun when he Declines — NORTH. 23½ DEGREES. The Moon Declines | | | NORTH. 20 DEGREES. The Moon Declines | | | NORTH. 10 DEGREES. The Moon Declines | | | 0 DEGREES. The Moon Declines | | | SOUTH. 10 DEGREES. The Moon Declines | | | SOUTH. 20 DEGREES. The Moon Declines | | | SOUTH. 23½ DEGREES. The Moon Declines | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 30° in 1 Group. | 0° Equator. | 30° in 2 Group. | 30° in 1 Group. | 0° Equator. | 30° in 2 Group. | 30° in 1 Group. | 0° Equator. | 30° in 2 Group. | 30° in 1 Group. | 0° Equator. | 30° in 2 Group. | 30° in 1 Group. | 0° Equator. | 30° in 2 Group. | 30° in 1 Group. | 0° Equator. | 30° in 2 Group. | 30° in 1 Group. | 0° Equator. | 30° in 2 Group. |
| | deg. | deg. | deg. | deg. | deg. | deg. | deg | deg | deg. | deg. | deg. | deg. | deg | deg. | deg. | deg. | deg. | deg. | deg. | deg. | deg. |
| 1 | 78 | 83 | 88 | 80 | 85½ | *89½* | *86½* | *88* | *82* | *87* | *81½* | *75½* | *80½* | *75* | *69* | *74½* | *69* | *63* | *72* | *67* | *61* |
| 2 | 86 | *89* | *84½* | 88 | *87* | *82* | *85* | *80* | *74½* | *78½* | *73* | *67½* | *72* | *60½* | *60½* | *66* | *60½* | *54½* | *63½* | *58½* | *52½* |
| 3 | *86½* | *82* | *78* | *84* | *79½* | *75* | *76½* | *72* | *67* | *69½* | *64½* | *59½* | *62½* | *58* | *52½* | *56½* | *51½* | *46* | *54½* | *49½* | *44* |
| 4 | *78* | *74½* | *71½* | *75* | *71½* | *68½* | *67* | *63½* | *59½* | *59½* | *55½* | *51* | *52* | *48* | *43* | *46* | *41* | *36* | *43½* | *39* | *33½* |
| 5 | 70½ | 68½ | *66* | *67* | *65* | *62½* | *59* | *56* | *53* | *50* | *47* | *43½* | *42½* | *38* | *35* | *35* | *30½* | *26* | *32* | *28* | *24* |
| 6 | *65½* | *64* | *63½* | *62* | *60½* | *60* | *52½* | *51* | *50* | *43* | *41* | *40* | *33½* | *31½* | *30* | *24½* | *21½* | *20* | *21½* | *18* | *16½* |
| 7 | *63½* | *64* | *65½* | 60 | *60½* | *62* | *50* | *51* | *52½* | *40* | *41* | *43* | *30* | *31½* | *33½* | *20* | *21½* | *24½* | *16½* | *18* | *21½* |
| 8 | *66* | *68½* | *70½* | *62½* | *65* | *67* | *53* | *56* | *59* | *43½* | *47* | *50* | *35* | *38½* | *42½* | *26* | *30½* | *35* | *24* | *28* | *32* |
| 9 | *73* | 76 | *80½* | *69½* | *73* | *77½* | *61* | *65* | *69½* | *52* | *57* | *62½* | *45* | *50* | *55* | *38* | *43* | *49* | *36* | *41* | *47* |
| 10 | *80½* | *85½* | 89½ | *77½* | *83* | *88* | 70 | *75½* | *81* | *62½* | *68½* | *74* | *56* | *62* | *67½* | *49½* | *55½* | *61½* | *47½* | *53½* | *59* |
| 11 | 89½ | 84½ | 79 | *88* | 87 | 80½ | *81½* | *80½* | 88 | *74½* | *80* | *85½* | *68* | *73½* | *79* | *62* | *67½* | *73* | *60* | *65½* | *71* |
| 12 | 80½ | 75 | 70 | 82½ | 77½ | 72 | 89 | 84 | 78 | *84* | 90 | 84½ | *78* | *83½* | *89* | *71½* | 77 | *82½* | *69½* | *75* | *80* |
| 13 | 72 | 67 | 61 | 74½ | 69 | 63 | 80½ | 75 | 69 | 87 | 81½ | 75½ | *86½* | 88 | 82 | *80* | *85½* | 89½ | *78* | *83* | *88* |
| 14 | 63½ | 58½ | 52½ | 66 | 60½ | 54½ | 72 | 66½ | 60½ | 78½ | 73 | 67½ | 85 | 80 | 74½ | *88* | 87 | 82 | *86* | 89 | 84½ |
| 15 | 54½ | 49½ | 44 | 56½ | 51½ | 46 | 62½ | 58 | 52½ | 69½ | 64½ | 59½ | 76½ | 72 | 67 | 84 | 79½ | 75 | 86½ | 82 | 78 |
| 16 | 43½ | 39 | 33½ | 46 | 41 | 36 | 52 | 48 | 43 | 59½ | 55½ | 51 | 67 | 63½ | 59½ | 75 | 71½ | 68½ | 78 | 74½ | 71½ |
| 17 | 32 | 28 | 24 | 35 | 30½ | 26 | 42½ | 38 | 35 | 50 | 47 | 43½ | 59 | 56 | 53 | 67 | 65 | 62½ | 71½ | 68½ | 66 |
| 18 | 21½ | 18 | 16½ | 24½ | 21½ | 20 | 33½ | 31½ | 30 | 43 | 41 | 40 | 52½ | 51 | 50 | 62 | 60½ | 60 | 65½ | 64 | 63½ |
| 19 | 16½ | 18 | 21½ | 20 | 21½ | 24½ | 30 | 31½ | 33½ | 40 | 41 | 43 | 50 | 51 | 52½ | 60 | 60½ | 62 | 63½ | 64 | 65½ |
| 20 | 24 | 28 | 32 | 26 | 30½ | 35 | 35 | 38½ | 42½ | 43½ | 47 | 50 | 53 | 56 | 59 | 62½ | 65 | 67 | 66 | 68½ | 70½ |
| 21 | 36 | 41 | 47 | 38 | 43 | 49 | 45 | 50 | 55 | 52 | 57 | 62½ | 61 | 65 | 69½ | 69½ | 73 | 77½ | 73 | 76 | 80½ |
| 22 | 47½ | 53½ | 59 | 49½ | 55½ | 61½ | 56 | 62 | 67½ | 62½ | 68½ | 74 | 70 | 75½ | 81 | 77½ | 83 | 88 | 80½ | 85½ | *89½* |
| 23 | 60 | 65½ | 71 | 62 | 67½ | 73 | 68 | 73½ | 79 | 74½ | 80 | 85½ | 81½ | 86½ | *88* | 88 | *87* | *80½* | *89½* | *84½* | 79 |
| 24 | 69½ | 75 | 80 | 71½ | 77 | 82½ | 78 | 83½ | 89 | 84 | 90 | *84½* | *89* | *84* | *78* | *82½* | *77½* | *72* | *80½* | *75* | *70* |

NOTE.—The italicized figures in this table refer to lower, the non-italicized to upper transit of Sun.

then have to be corrected accordingly in order to find "mean high water" and "mean low water."

According to Tables 22, 23, 24 and 25, the zenith distances of the heavenly bodies were entered in the first reduction for each observation; then the second reductions were made and grouped in such a way as to render apparent the amount of the various heavenly influences. The following tables show the means thus obtained for the height of low water.

*The Low Water Observations Grouped so as to Render Apparent the Influence of Lunar Parallax on the Height of Low Water at Cape Henlopen.*

MEANS OF SECOND REDUCTION.

*Table 27.*—The Higher Parallaxes.

| Number of Observations | Reading of Gauge. | Moon's Parallax | Zenith Distance of Moon | Zenith Distance of Sun. |
|---|---|---|---|---|
| | feet. | minutes. | degrees. | degrees. |
| 114 | —0·20 | 58·5 | 83 | 35 |
| 83 | —0·48 | 58·7 | 83 | 54½ |
| 112 | —0·62 | 58·8 | 84 | 64¾ |
| 101 | —0·78 | 59·2 | 83¼ | 74½ |
| 120 | —0·88 | 59·2 | 84¼ | 84½ |

*Table 28.*—The Lower Parallaxes.

| Number of Observations. | Reading of Gauge. | Moon's Parallax. | Zenith Distance of Moon. | Zenith Distance of Sun. |
|---|---|---|---|---|
| | feet | minutes. | degrees. | degrees. |
| 137 | +0·25 | 55·0 | 83 | 35 |
| 72 | —0·01 | 54·9 | 82 | 54½ |
| 108 | —0·21 | 55·0 | 83 | 64¾ |
| 92 | —0·40 | 54·9 | 83½ | 74½ |
| 93 | —0·46 | 54·9 | 83½ | 84½ |

*The Low Water Observations Grouped so as to Render Apparent the Influence of Lunar Zenith Distance on the Height of Low Water at Cape Henlopen.*

MEANS OF SECOND REDUCTION.

*Table 29.*—The Greater Lunar Zenith Distances.

| Number of Observations. | Reading of Gauge. | Moon's Parallax. | Zenith Distance of Moon. | Zenith Distance of Sun. |
|---|---|---|---|---|
| | feet. | minutes. | degrees | degrees. |
| 126 | —0·06 | 56·5 | 86 | 32 |
| 69 | —0·27 | 57·2 | 86 | 54¾ |
| 120 | —0·45 | 57·0 | 86½ | 65 |
| 101 | —0·65 | 57·1 | 86 | 74½ |
| 120 | —0·66 | 57·6 | 86½ | 84½ |

*Table 30.*—The Smaller Lunar Zenith Distances.

| Number of Observations. | Reading of Gauge. | Moon's Parallax. | Zenith Distance of Moon. | Zenith Distance of Sun. |
|---|---|---|---|---|
| | feet. | minutes | degrees. | degrees. |
| 125 | +0·16 | 56·6 | 80 | 38 |
| 86 | —0·25 | 56·7 | 79½ | 54½ |
| 100 | —0·39 | 56·8 | 80 | 64½ |
| 92 | —0·55 | 57·2 | 80 | 74½ |
| 93 | —0·74 | 57·1 | 80½ | 84½ |

It will be noticed that the above tables for low water are arranged for progressive values of solar zenith distance, which is

the most decisive factor in the variations of height of low water, the lunar zenith distance from low water, and consequently the lunar contribution towards it varying within comparatively small limits only. In Tables 27 and 28, the differences in lunar zenith distance are very slight; the difference then, appearing in the height of low water for the same mean solar zenith distance in the two tables, must be attributed almost entirely to the difference in lunar parallax; in a similar way, the differences in height appearing in Tables 29 and 30 must be attributed to the differences in lunar zenith distance. The summing up of Tables 27 and 28 thus renders the result that for a difference of 19·7 minutes in lunar parallax there is a difference of 2·13 feet in height of low water, or "for a difference of 1 minute in lunar parallax, there is a difference of about 0·11 feet in height of low water."

Again, the summing up of Tables 29 and 30 renders the result that between 80° and 86° of lunar zenith distance, there is a difference of 0·05 feet; that is to say, that the point corresponding to 80° on the lunar wave is that much elevated above the one corresponding to 86°.

Table 31 renders the general means of all low water observations grouped according to solar zenith distance, and Table 32 renders these means as corrected to 57 minutes of parallax and 83° of lunar zenith distance; the figures of this table, therefore, can be utilized to construct the solar wave corresponding to mean sidereal conditions.

*Table 31.*—General Means of all Observations of Height of Low Water.

| Number of Observations. | Reading of Gauge | Moon's Parallax. | Zenith Distance of Moon | Zenith Distance of Sun. |
|---|---|---|---|---|
| | feet. | minutes. | degrees. | degrees. |
| 251 | +0·05 | 56·6 | 83 | 35 |
| 155 | —0·26 | 57·0 | 82½ | 54½ |
| 220 | —0·42 | 56·9 | 83½ | 64¾ |
| 193 | —0·60 | 57·2 | 83½ | 74½ |
| 213 | —0·70 | 57·3 | 84 | 84½ |

*Table 32.*—General Means as Corrected to Mean Parallax and Mean Lunar Zenith Distance.

| Number of Observations. | Reading of Gauge. | Moon's Parallax. | Zenith Distance of Moon. | Zenith Distance of Sun. |
|---|---|---|---|---|
| | feet. | minutes. | degrees. | degrees. |
| 251 | +0·01 | 57·0 | 83 | 35 |
| 155 | —0·26 | 57·0 | 83 | 54½ |
| 220 | —0·43 | 57·0 | 83 | 64¾ |
| 193 | —0·58 | 57·0 | 83 | 74½ |
| 213 | —0·66 | 57·0 | 83 | 84½ |
| Means: | —0·38 | 57·0 | 83 | 62$\frac{3}{5}$ |

The mean of Table 32 has to be reduced to the mean solar

zenith distance, in order to obtain mean low water, and from the heights for 54½° and 64¾° solar zenith distance contained in the table, we find that the required reduction amounts to + 0·01, and we therefore obtain as a mean from 1,032 observations:

Height of mean low water at Cape Henlopen — 0·37.

The sidereal conditions for the five positions of Table 32 being equal, with the exception of solar zenith distance, which is a different one for each position, it is clear that the differences in reading must be ascribed to such differences in solar zenith distance. By platting the figures of Table 32 in a suitable way, a diagram is therefore obtained of the contour of the solar component wave. This platting has been executed in *Fig. 22*, the readings of Table 32 having previously been reduced to "*mean low water equal to zero*," by simply adding 0·37 to each of them.

The following tables show the means derived from the second reduction of high water observations, and grouped so as to render apparent the amount of the various heavenly influences.

*The High Water Observations Grouped so as to Render Apparent the Influence of Lunar Parallax on the Height of High Water at Cape Henlopen.*

MEANS OF SECOND REDUCTION.

*Table 33.*—The Higher Parallaxes.

| Number of Observations. | Reading of Gauge. | Moon's Parallax. | Zenith Distance of Moon. | Zenith Distance of Sun. |
|---|---|---|---|---|
| | feet. | minutes. | degrees. | degrees. |
| 58 | 4·85 | 59·6 | 17 | 46 |
| 115 | 4·39 | 58·8 | 24⅓ | 49 |
| 85 | 4·17 | 58·6 | 34½ | 52 |
| 74 | 3·80 | 58·6 | 45 | 62½ |
| 104 | 3·54 | 58·8 | 55 | 68 |
| 51 | 3·43 | 59·9 | 63 | 68½ |

*Table 34.*—The Lower Parallaxes.

| Number of Observations. | Reading of Gauge. | Moon's Parallax. | Zenith Distance of Moon. | Zenith Distance of Sun. |
|---|---|---|---|---|
| | feet. | minutes. | degrees. | degrees. |
| 77 | 3·94 | 54·6 | 16½ | 50 |
| 109 | 3·90 | 55·0 | 24¼ | 53½ |
| 72 | 3·74 | 55·3 | 35 | 58½ |
| 62 | 3·52 | 55·2 | 45 | 61 |
| 106 | 3·31 | 55·0 | 56 | 67 |
| 70 | 2·85 | 54·7 | 63½ | 70 |

*The High Water Observations Grouped so as to Render Apparent the Influence of Solar Zenith Distance on the Height of High Water at Cape Henlopen.*

MEANS OF SECOND REDUCTION.

*Table 35.*—The Greater Solar Zenith Distances.

| Number of Observations. | Reading of Gauge. | Moon's Parallax. | Zenith Distance of Moon. | Zenith Distance of Sun. |
|---|---|---|---|---|
| | feet. | minutes. | degrees. | degrees. |
| 78 | 4·14 | 56·4 | 17 | 63 |
| 117 | 4·00 | 56·7 | 24½ | 68½ |
| 91 | 3·70 | 56·8 | 34¾ | 68 |
| 49 | 3·31 | 56·9 | 44¾ | 80 |
| 93 | 3·26 | 56·9 | 55⅔ | 79 |
| 52 | 3·01 | 56·3 | 63 | 78½ |

*Table 36.*—The Smaller Solar Zenith Distances.

| Number of Observations. | Reading of Gauge. | Moon's Parallax. | Zenith Distance of Moon. | Zenith Distance of Sun. |
|---|---|---|---|---|
| | feet. | minutes. | degrees | degrees. |
| 57 | 4·59 | 57·2 | 16⅓ | 28 |
| 107 | 4·32 | 57·2 | 24 | 32½ |
| 66 | 4·35 | 57·5 | 34½ | 38 |
| 87 | 3·87 | 57·1 | 45 | 51½ |
| 117 | 3·55 | 56·8 | 55½ | 58 |
| 69 | 3·16 | 57·3 | 63⅓ | 62⅔ |

From Tables 33 and 34, we derive the following differences in height for the corresponding differences in lunar parallax:

| Difference in Lunar Parallax. | Difference in Reading of Gauge. |
|---|---|
| minutes. | feet. |
| 5·0 | 0·91 |
| 3·8 | 0·49 |
| 3·3 | 0·43 |
| 3·4 | 0·28 |
| 3·8 | 0·23 |
| 5·2 | 0·58 |

The solar zenith distances in the two tables do not, however, agree sufficiently closely to permit of deducing direct from these figures the influences of lunar parallax. The required correction we may take from the contour of the solar wave, *Fig. 22*, and we then obtain:

*Table 37.*—The Influence of Lunar Parallax on the Height of High Water at Cape Henlopen, as deduced from Tables 33 and 34:

| Lunar Zenith Distance. | Difference in Parallax. | Corresponding Difference in Reading of Gauge. | Difference in Reading of Gauge per Minute of Parallax. |
|---|---|---|---|
| 16¾ | 5·0 | 0·86 | 0·17 |
| 24¼ | 3·8 | 0·43 | 0·11 |
| 34¾ | 3·3 | 0·33 | 0·10 |
| 45 | 3·4 | 0·30 | 0·09 |
| 55½ | 3·8 | 0.24 | 0·06 |
| 63 | 5·2 | 0·56 | 0·11 |
| Means: | 4·1 | 0·45 | 0·11 |

The last column of this table, containing the differences in height per 1 minute of lunar parallax, seems to indicate that during the lesser lunar zenith distances the influence exercised by lunar parallax is more pronounced than during the greater lunar zenith distances, an indication which is in perfect accordance with theory. The results in this direction, however, are not sufficiently well defined to make any distinction, and we shall, therefore, assume the general mean rendered by Table 37, of 0·11 per minute of parallax for all positions of the Moon. This value is, as will be remembered, precisely the same that was found for the influence of lunar parallax on the height of low water.

The differences in height of high water caused by solar zenith distances, as set forth in Tables 35 and 36, afford a check on the correctness of the solar wave as constructed from the low water observations. If the heights in both tables are corrected to an equal parallax, then we derive

| Solar Zenith Distance. Table 35. | Solar Zenith Distance. Table 36. | Difference in Reading of Gauge, due to Difference in Adjoining Solar Zenith Distances. |
|---|---|---|
| degrees. | degrees. | |
| 28 | 63 | 0·36 |
| 32½ | 68½ | 0·27 |
| 38 | 68 | 0·57 |
| 51½ | 80 | 0·54 |
| 58 | 79 | 0·30 |
| 62⅔ | 78½ | 0·05 |

A comparison of these differences with the differences in height between the points in question of the solar wave (*Fig. 22*) will show that on the general average both agree tolerably well.

The following tables render the general means of the height of high water:

*Table 38.*—General Means of all Observations of Height of High Water.

| Number of Observations. | Reading of Gauge. | Moon's Parallax. | Zenith Distance of Moon. | Zenith Distance of Sun. |
|---|---|---|---|---|
| | feet. | minutes. | degrees. | degrees. |
| 135 | 4·33 | 56·7 | 16⅔ | 48½ |
| 224 | 4·15 | 57·0 | 24⅓ | 51 |
| 157 | 3·97 | 57·1 | 34¾ | 55 |
| 136 | 3·67 | 57·0 | 45 | 61⅔ |
| 210 | 3·42 | 56·8 | 55½ | 67½ |
| 121 | 3·09 | 56·9 | 63 | 69½ |

*Table 39.*—General Means as Corrected to Mean Lunar Parallax and Mean Solar Zenith distance.

| Number of Observation. | Reading of Gauge. | Moon's Parallax. | Zenith Distance of Moon. | Zenith Distance of Sun. |
|---|---|---|---|---|
| | feet. | minutes. | degrees. | degrees. |
| 135 | 4·23 | 57·0 | 16⅔ | 57 |
| 224 | 4·06 | 57·0 | 24⅓ | 57 |
| 157 | 3·93 | 57·0 | 34¾ | 57 |
| 136 | 3·75 | 57·0 | 45 | 57 |
| 210 | 3·61 | 57·0 | 55½ | 57 |
| 121 | 3·31 | 57·0 | 63 | 57 |
| Means: | 3·81 | 57·0 | 39⅝ | 57 |

We obtain from Table 39 as a mean of 983 observations,

Height of mean high water at Cape Henlopen = 3·81

It will be noticed that the above tables for high water are arranged for progressive values of lunar zenith distance. In Table 39, the sidereal conditions are equal throughout with the exception of lunar zenith distance, the differences in height (or reading,) therefore, appearing in this table, must be due to the differences in lunar zenith distance, and we are thus enabled from the general means rendered by this table to construct the contour of the lunar wave. This construction has been made in *Fig 23*, the readings of Table 39 having been previously reduced to "*mean low water equal to zero*," by simply adding 0·37 to each of them.

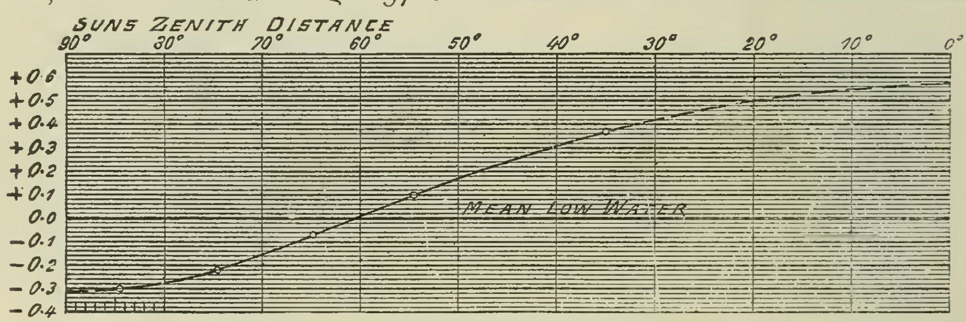



*Fig. 22.*—The Solar Wave as Constructed from the Corrected General Means of 1,032 Low Water Observations at Cape Henlopen

Lunar parallax . . . . . . . . . . . . . . . . . . = 57′
Moon's Zenith distance . . . . . . . . . . . . . . = 83°

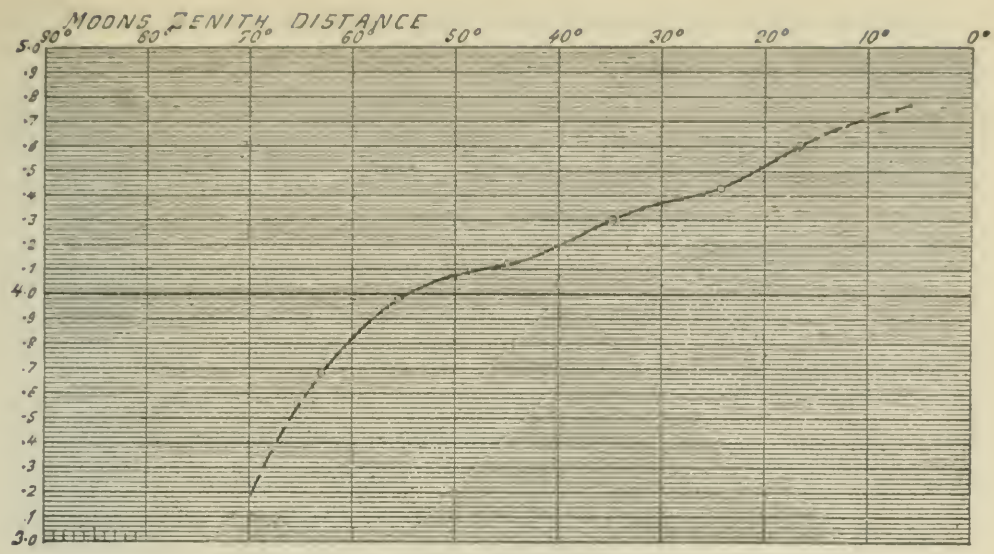



*Fig. 23.*—The Lunar Wave as Constructed from the Corrected General Means of 983 High Water Observations at Cape Henlopen

Lunar parallax . . . . . . . . . . . . . . . . . . = 57′
Sun's zenith distance . . . . . . . . . . . . . . . . = 57°

While the contour of the solar wave is a regular curve, that of the lunar wave is very irregular, a result which the writer is not in a position to explain beyond this, that a greater number of observations than were at his disposal would probably yield a more regular curve.

Before giving an example, showing the way in which the curves of *Fig. 22* and *Fig. 23* are utilized in order to make predictions, the corrections which, as found before, have to be applied outside of them are herewith recapitulated as follows :

*Corrections for Height of Low Water.*

For 1 minute additional lunar parallax, there is to be subtracted 0·11 of the height.

For 1° additional of lunar zenith distance, there is to be subtracted 0·01 of the height.

*Correction for Height of High Water.*

For 1 minute additional lunar parallax, there is to be added 0·11 to the height.

The height of mean high water above mean low water, in other words, the mean rise and fall, has been found as follows :

Mean rise and fall at Cape Henlopen, . . . . . . . . . . 4·18

The following is an example illustrating the way of predicting the height of high and low water:

*Prediction of the Height of High Water on the Evening of June 26th, and the Height of Low Water on the Morning of June 27, 1884, at Cape Henlopen.*

| | |
|---|---|
| Hour of Moon's transit (upper), . . . . . . . . . . . | 2nd |
| Moon's declination, . . . . . . . . . . . . . . . . . | 19° N. |
| Sun's declination, . . . . . . . . . . . . . . . . . . | 21° N. |
| Moon's parallax, . . . . . . . . . . . . . . . . . . | 61′ |

From these figures we derive:

| | | |
|---|---|---|
| Zenith distance of Moon | from high water (Table 22), . . . | 21° |
| | from low water (Table 23), . . . | 83° |
| Zenith distance of Sun | from high water (Table 24), . . . | 25½° |
| | from low water (Table 25), . . . | 85° |

In taking these zenith distances from the tables, it has to be remembered that the high and the low water, which we are about to predict, are incident on an upper lunar transit during Northern lunar declination, and that therefore they belong to the second lunar group.

If now we take from our diagrams, *Fig. 22* and *Fig. 23*, the solar and lunar elevations, corresponding to the above found zenith distances, introducing also the other corrections, then we obtain:

*Height of High Water.*

| | |
|---|---|
| (1.) Lunar contribution, . . . . . . . . . . . . . . . | 4·50 |
| (2.) Solar contribution, being the difference between the elevation at 57° and at 25½° of the solar wave, . . . | + 0·40 |
| (3.) Correction for 61′ lunar parallax, . . . . . . . . . | + 0·44 |
| Predicted height, . . . . . . . . . . . . . . | 5·34 |

*Height of Low Water.*

| | |
|---|---|
| (1.) Solar contribution, . . . . . . . . . . . . . . . | — 0·30 |
| (2.) Correction for lunar zenith distance, . . . . . . . | |
| (3.) Correction for 61′ lunar parallax, . . . . . . . . . | — 0·44 |
| Predicted height, . . . . . . . . . . . . . . . | — 0·74 |

The actually observed heights were:

| | |
|---|---|
| High water, . . . . . . . . . . . . . . . . . . . | 5·54 |
| Low water, . . . . . . . . . . . . . . . . . . . | — 1·01 |

all of which figures refer to the plane of mean low water.

The limited number of observations available have not allowed, as mentioned before, to determine the influence of solar distance, neither has it been possible to determine the influence of winds, which, as far as prediction is concerned, might possibly be utilized on the basis of the prevailing direction and average force for certain periods of the year. The writer, therefore, desires to say in conclusion that his object in publishing this paper, mainly was to call attention to a system of prediction, the application of which, on a broader basis than was at his disposal, will in his opinion prove fruitful. Conscious of the above mentioned and other shortcomings, he does not claim for the practical example given any more than results of ordinary value, obtainable doubtless also by other methods with the same degree of exactitude.

---

CRUSHING LIMIT OF COLUMNS.—In preparing a plan for an electric lighthouse M. Bourdais, the architect of the Palace of the Trocadero, investigated the height to which a column of different materials could be raised without crushing under its own weight. The weight of a pyramid with a square base may be expressed by the equation :

$$P = D^2 \frac{h}{3} \delta$$

in which $D$ represents the side of the base of the pyramid, $h$ the height, and $\delta$ the density.

The resistance is: $R = \frac{P}{D^2}$

Hence $R = \frac{1}{3} h \delta$

$$h = \frac{3R}{\delta}.$$

If we take for the limiting value of $R$ one-sixth of the load, which produces crushing in iron, and one-twentieth for different varieties of stone, we may deduce the following table:

| MATERIAL. | R. | $\delta$. | H. |
|---|---|---|---|
| Porphyry, | 2,470,000 | 2,870 | 2,550 metres. |
| Iron, | 6,000,000 | 7,800 | 2,280 " |
| Granite, | 800,000 | 2,700 | 900 " |
| Bagneux freestone, | 440,000 | 2,400 | 540 " |
| Saint nom stone, | 230,000 | 2,300 | 300 " |
| Banc royal, | 60,000 | 1,700 | 100 " |
| Vergelé, | 30,000 | 1,500 | 60 " |

Such are the practical limits to which a pyramid might be raised in the respective materials. It is evident that the Egyptians, in the great pyramid of Cheops, stopped far below the limit. If the prismatic form were adopted, the height could be only one-third as great.—*Lumière Électrique*, February 21, 1885.

# CYLINDER CONDENSATION IN STEAM ENGINES. AN EXPERIMENTAL INVESTIGATION.

BY CHAS. L. GATELY, M. E., AND ALVIN P. KLETZSCH, M. E.

[*Presented to the American Association for Advancement of Science; Ann Arbor Meeting, 1885, with an Introduction by* PROFESSOR R. H. THURSTON.]

[*Continued from October Issue, page 298.*]

### 9. THE METER.

The water meter used to indicate the amount of feed water that was pumped into the boiler was carefully standardized by allowing exactly 20 cubic feet of water to flow through.

It was necessary to use a small barrel, owing to the position in which the meter was placed. It will be seen from the data taken at the time, that in 20 cubic feet the difference in the actual and calculated number of pounds flowed through is only three pounds, this difference being no doubt due to error in observing the readings, rather than to any fault of the meter itself. The following figures are the weights of the water and barrel, and of the barrel itself:

| | | |
|---|---|---|
| First barrel full, | 232· | |
| First barrel empty, | | 37· |
| Second barrel full, | 176· | |
| Second barrel empty, | | 37·5 |
| Third barrel full, | 174· | |
| Third barrel empty, | | 37·5 |
| Fourth barrel full, | 177·5 | |
| Fourth barrel empty, | | 37·5 |
| Fifth barrel full, | 155·5 | |
| Fifth barrel empty, | | 37·5 |
| Sixth barrel full, | 188·5 | |
| Sixth barrel empty, | | 37·5 |
| Seventh barrel full, | 188·5 | |
| Seventh barrel empty, | | 38· |
| Eighth barrel full, | 163· | |
| Eighth barrel empty, | | 38· |
| Ninth barrel full, | 128·5 | |
| Ninth barrel empty, | | 38· |
| Total, | 1583·5 | 338·5 |
| Difference, | 1245. pounds. | |

The thermometers used were new and made by J. W. Queen & Co., Philadelphia, and as by comparison with each other they were found alike, further standardizing was not deemed necessary.

### 10. THE WEIR.

The tumbling bay was very carefully tested, in order to ascertain the coefficient of contraction, or the ratio which the cross section of the most contracted part of the steam flowing from the notch, bears to the area of the notch at a given head.

The test was made as follows: Water was allowed to flow through the condenser into the weir; after the surface became calm the height of water over the notch was read, the time noted and water allowed to flow over for two minutes, all of which was caught and weighed. This was repeated four times, and the data taken; together with the method used in calculating the average coefficient of contraction is given below:

TEST NO. 1.

| | | |
|---|---|---|
| Weight of barrel No. 1, full, | 267·5 | |
| " " " 1, empty, | | 40·5 |
| " " " 2, full, | 243·5 | |
| " " " 2, empty, | | 36·5 |
| " " " 3, full, | 146· | |
| " " " 3, empty, | | 36·5 |
| Total, | 657· | 113·5 |
| Difference, | 543·5 pounds. | |

Breadth of notch $= b = 6$ inches $= 0·5$ foot.
Height over notch board $= h = ·125$ foot.
Time of flow $= 2$ minutes.
Flow in cubic feet, per second,

$$= \frac{543·5}{62·4 \times 120} = ·07258 = Q.$$

Substituting these values in Rankine's Formula, page 93, of "The Steam Engine," which is

$$Q = \tfrac{2}{3}\, c\, b\, h \sqrt{2\, g\, h}$$

Where $Q$, $b$ and $h$, are, as stated before, $2\,g$ being 64·4 and $\sqrt{2\,g\,h}$, the velocity due to the height $h$ and $c$ the coefficient of contraction to be found, hence

$$\cdot07258\ b\ h = \cdot5 \times \cdot125 = \cdot0625$$
$$\sqrt{2\,g\,h} = \sqrt{64\cdot4 \times \cdot125} = 2\cdot837$$
$$b\,h\,\sqrt{2\,g\,h} = \cdot0625 \times 2\cdot837 = \cdot1773$$
$$c = \tfrac{3}{2}\,Q\,\frac{1}{b\,h\,\sqrt{2\,g\,h}} = \tfrac{3}{2} \times \cdot07258 \times \frac{1}{\cdot1773}$$
$$c = \cdot614.$$

TEST NO. 2.

| | | |
|---|---|---|
| Weight of barrel No. 1, full, . . . . . . . . . . | 252·5 | |
| " " " 1, empty, . . . . . . . . | | 40·5 |
| " " " 2, full, . . . . . . . . . . | 188· | |
| " " " 2, empty, . . . . . . . . | | 36·5 |
| " " " 3, full, . . . . . . . . . . | 113·5 | |
| " " " 3, empty, . . . . . . . . | | 26·5 |
| " " " 4, full, . . . . . . . . . . | 137· | |
| " " " 4, empty, . . . . . . . . | | 26·5 |
| Total, . . . . . . . . . . . . . . . . | 691· | 130· |
| Net flow, . . . . . . . . . . . . . . . | 561· pounds. | |

Here $b$ = 6· inches.
$h$ = 1·5 inches.
Time of flow = 2 minutes.

and substituting in formula as in previous test

$$c = \cdot633$$

TEST NO. 3.

| | | |
|---|---|---|
| Weight of barrel No. 1, full, . . . . . . . . . . | 445· | |
| " " " 1, empty, . . . . . . . . | | 61· |
| " " " 2, full, . . . . . . . . . . | 151· | |
| " " " 2, empty, . . . . . . . . | | 37· |
| Total, . . . . . . . . . . . . . . . . | 596· | 98· |
| Net flow, . . . . . . . . . . . . . . . | 498· pounds. | |

Here $b$ = 6· inches.
$h$ = 1·416 inches.
And time of flow = 2 minutes.

Hence

$$c = \cdot6133$$

TEST NO. 4.

| | | |
|---|---|---|
| Weight of barrel No. 1, full, . . . . . . . . . . | 412·5 | |
| " " " 1, empty, . . . . . . . . | | 61·5 |
| " " " 2, full, . . . . . . . . . . | 201·5 | |
| " " " 2, empty, . . . . . . . . | | 38· |
| Total, . . . . . . . . . . . . . . . . | 614· | 99·5 |
| Net flow, . . . . . . . . . . . . . . . | 514·5 pounds. | |

Here $b = 6{\cdot}0$ inches.

$h = 1{\cdot}416$ inches.

And time of flow = 2 minutes.

Hence

$$c = {\cdot}6233$$

Average coefficient of contraction of tests No. 1, No. 2, No. 3 and No. 4, would give

$$c = {\cdot}6233$$

This value for $c$ being used to calculate the flow from the condenser in the trials.

A Fairbank's standard platform scale was used in weighing the power developed by the brake and, by careful comparison with others, was found to be correct.

The weight registered by the scales, owing to a part of the weight of the brake falling on it, was found by weighing the upright standards by themselves, and then the beams and tie-rods, which formed the levers of the brake, the design of which was such, that all the weight of the standards and one-half the weight of the beams, etc., would directly tend to increase the reading, hence this had to be ascertained in order to get the true scale reading. It amounted to 202·5 pounds, which is to be subtracted from all the scale readings in the logs of the trials.

| | | |
|---|---|---|
| Weight of uprights, etc., . . . . . . . . . . . . | 131·5 | pounds. |
| One-half weight of beams, tie-rods, etc., . . . . | 71· | " |
| Total, . . . . . . . . . . . . . . . . . | 202·5 | " |

A Hawkin's speed counter was used to record the total number of revolutions made by the engine during each trial, receiving its motion from the eccentric rod.

As before stated, leakage of piston was looked for, and its non-existence determined first by disconnecting the valve gear, stopping the piston about midway of the stroke, and introducing water through one of the steam ports, at the same time closing the exhaust at that, and opening it at the other end, so that any water getting by the piston would run out through that port; but upon repeated trials it was found to be water-tight.

Next, steam was admitted at one end with all the other valves closed, and the indicator cock at the other end was opened, but no steam issued from it.

The clearance was not determined by us, but obtained from Mr. Wm. A. Harris, the builder; he gave the following figures for all his engines of this size, 297·4 cubic inches, for each end.

II. METHOD OF OPERATION OF ENGINE, BOILERS AND APPARATUS.

In running the trials, in order to preserve constant conditions of pressure, speed and ratio of expansion, the greatest care and watchfulness was required. The fires in the furnaces were thoroughly cleaned at night. Fires were restarted at 6 o'clock in the morning, so that by 7·30 they were burning freely. Before beginning a trial, the pressure was allowed to run up a few pounds higher than that which was to be run, the regulator was then blocked up to a point which would give the required cut-off, as determined by previous observations, and the different points indicated by marks upon the upright rod of the regulator. The throttle was then opened, and the pressure of the brake applied, until the speed was as required.

The fireman and his assistant were then cautioned to keep the pressure constant. We were fortunate in securing the services of the fireman who had had the care of the boilers and engine since they were put down. The only condition remaining was the speed, which was entirely controlled by the brake.

When the proper speed was reached, and all was ready for the start, the height of water in the boiler gauges noticed, meter reading taken, the speed counter read and the time recorded from which instant the trial began, the longest run being three hours, and the shortest one-and-a-half hours. Indicator cards were taken simultaneously from each end of the cylinder as soon after the trial began as it was possible, and continued throughout the run at intervals of every fifteen minutes in the longer trials, and every ten minutes in the shorter. Besides these, the following observations were taken at the same time, as shown by the revised logs of trials which are given :

Temperature of feed water.
Temperature of injection water.
Temperature of weir.
Pressure on brake scales.
Pressure of boiler.
Vacuum in condenser.

Head of water over notch in weir.

These readings were also taken throughout the trials at regular intervals, as shown by the logs.

12. SPECIAL POINTS.

Calorimeter tests were made during each trial, to determine the percentage of priming, and the records will be found annexed to the logs of trial.

The water used to keep the brake pulley cool entered on one side of the drum or pulley, and was discharged on the other side, by means of a scoop, into the hot well from which it was pumped into the boilers, often entering the hot well at a temperature over 100° Fahrenheit, a rise in some cases of 40°. In the every-day work of the engine, the condensing water is used for feed, but in our trials the pipe leading from the discharge pipe to the hot well was closed, so that all the water would pass through the weir as previously detailed.

In closing the trials, particular care was taken that the height of the water in the boiler gauges should exactly correspond with the height at the beginning, so that the meter readings would show the amount of water evaporated. The final meter reading was then taken and the trial concluded.

The readings of the micrometer screw and hook gauge were repeated twice at each observation, to avoid errors entering from this cause, and not even in one instance did the height of the water over the notch vary by 0·001 of an inch.

Although we make no use of the brake readings in our calculations, they were taken in order to complete the data, for any future use to which it may be put. In test Nos. 3 and 4, Case I, which were made on Sunday, May 25th, it was found necessary to use three boilers. When making our preliminary examination, it was understood that we could not have the use of this third boiler, it being used during the week to supply steam to the mill, therefore the water meter was placed in the feed pipe between this and the two boilers that were regularly used, so that the water pumped into the third boiler would not show on the dial, hence in the logs of this trial the meter readings do not appear.

Deductions have to be made from the water as shown by the meter, to the extent of that which was allowed to flow through the

drip-pipe as previously mentioned. In order to ascertain the temperature of the feed water, together with that which was condensed and allowed to flow in the calorimeter trials, these amounts are entered in the last right hand column of each log.

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## CHAPTER III.

13. ACCOUNT OF THE EXPERIMENTAL INVESTIGATION IN DETAIL.

From the limited investigations of others, and from thermodynamics, it is clearly shown that variations of ratio of expansion, variation of piston speed or time of exposure, and variation of change of pressure or temperature, all exert some influence on the amount of cylinder condensation which takes place in the steam engine. The exact part which each of these causes play in an engine running under ordinary conditions of daily work has never been determined experimentally. With three variables entering the problem at the same time, it would be almost, if not absolutely, impossible to do it. Hence it is we divided our experiments into three parts, making four separate sets of tests, with the view of determining the effect of each of the above factors, and the variation caused by change in any of them. Starting with the effect on cylinder condensation, caused by the variation of the ratio of expansion or the point of cut-off, and running the condenser, we close a boiler pressure reasonably within the capacity for the two boilers to maintain during the heaviest one of the trials of the set, also selecting the speed at which, by trial, the engine was found to run best.

14. Speed and pressure were maintained as constant as possible throughout this whole set of four tests, as will be seen by referring to the logs of the trials given below; the ratio of expansion alone being allowed to vary, and that only during separate tests of each set. As before described, it was possible to secure this latter condition completely by blocking the regulator so that its action was prevented.

On May 24, 1884, at 10.16 A. M., with the boiler pressure at 62·5 pounds, the engine making 68 revolutions per minute, and cutting off at ·131 of the stroke, we commenced the first trial, stopping at 12.16 P. M., after a run of two hours.

The indicator diagrams taken, ten in number from each end, showed a constant cut-off, and, in fact, it could not be otherwise.

The greatest range in the boiler pressure was four and one-half pounds, with an average of 61·1 pounds per gauge, and with an average of 68·95 revolutions. The average revolutions and pressure carried, and the point at which the engine cut-off during the remaining three of this set of tests, are as follows:

| No. of Test. | Cut Off. | Pressure. | Revolutions. |
|---|---|---|---|
| 2 | ·330 | 60·1 | 67·32 |
| 3 | ·443 | 61·28 | 67·45 |
| 4 | ·589 | 56·83 | 68·26 |

giving 4·45 pounds as the greatest average variation in pressure, owing to insufficient boiler power in the fourth test, though a third one was used, when following beyond one-half stroke, and 1·63 revolutions as the greatest average variation in the speed of the engine per minute. This variation is so slight that its probable effect on the total condensation need hardly be calculated.

15. Below will be found the logs containing the data taken during each trial, together with the calorimeter trials made in connection with them:

CASE I.—CONDENSING.—VARIABLE CUT-OFF.

Table No. 1.
Test No. 1.
Date of Test, May 24th, 10·16 A. M. to 12·16 P. M.
Duration, 2 Hours.

*Conditions:* Constant Pressure. Constant Speed. Variable Cut-off.

| | Time. | Speed Counter. | Water Meter. | Height over Notch Board. | Temperature Feed Water. | Temperature Injection Water. | Temperature Weir. | Boiler Pressure. | Vacuum Gauge. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| Start, | 10·16 | 6875 | 5093·2 | 2·325 | | 66 | 118 | 62·5 | 22·5 | |
| | 10·31 | 7909 | | 2·322 | | 67 | 117 | 65· | 22·5 | |
| | 10 36 | 8255 | | | | | | | | |
| | 10·45 | 8875 | 5101·7 | 2·184 | 112 | 68 | 116 | 64· | 22·5 | $23\frac{10}{16}$ lbs. out. |
| | 11·00 | 9905 | | 2·214 | | 67 | 117 | 62· | 22 5 | |
| | 11·15 | 10935 | | 2·220 | 115 | 67 | 118 | 58· | 22 5 | 18½ lbs. ded'ct |
| | 11·30 | 11964 | | 2·214 | | 67 | 115 | 60· | 22·5 | |
| | 11·45 | 12999 | 5124· | 2·200 | 116 | 67 | 118 | 61· | 22· | 6½ lbs. ded'ct |
| | 12 00 | 14035 | 5134· | 2·200 | | 67 | 118 | 59·5 | 22·5 | |
| Finish, | 12·16 | 15150 | 5145·2 | 2·625 | | 68 | 110 | 58· | 23·5 | |

## Case I.—Condensing.—Variable Cut-off.

Table No. I.
Test No. 2.
Date of Test, May 24th, 2·36 P. M. to 4·31 P. M.
Duration, $1\frac{55}{60}$ Hours.

*Conditions:* Constant Pressure. Constant Speed. Variable Cut-off.

| | Time. | Speed Counter. | Water Meter. | Height over Notch Board. | Temperature Feed Water. | Temperature Injection Water. | Temperature Weir. | Boiler Pressure. | Vacuum Gauge. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| Start, | 2·36 | 15593 | 5161· | 3 252 | 144 | 71 | 138 | 62· | 20·5 | |
| | 2·46 | 16274 | | 3·146 | | 70 | 137 | 58· | 21·5 | |
| | 3·01 | 17272 | | 3·178 | | 71 | 133 | 60· | 21·5 | |
| | 3·16 | 18281 | | 3 581 | | 72 | 124 | 59· | 22· | |
| | 3·40 | 19896 | | 2 913 | | 72 | 141 | 62· | 20· | |
| | 3·46 | 20304 | | 3·132 | 136 | 72 | 138 | 62· | 20·5 | Deduct 25 lbs. |
| | 3·53 | 20780 | 5214· | 3 132 | | 72 | 137 | 59· | 21· | |
| | 4·04 | 21528 | | 3 127 | | 72 | 138 | 59· | 20 5 | |
| | 4·16 | 22344 | | 3·319 | | 72 | 133 | 59· | 21· | |
| Finish, | 4·31 | 20334 | 5276· | 3·170 | | 72 | 137 | 61· | | |

## Case I.—Condensing.—Variable Cut-off.

Table No. 1.
Test No. 3.
Date of Test, May 25th, from 11·32 to 1·02 P. M.
Duration, 1½ Hours.

*Conditions:* Constant Pressure. Constant Speed. Variable Cut-off.

| | Time. | Speed Counter. | Water Meter. | Height Over Notch Board. | Temperature Feed Water. | Temperature Injection Water. | Temperature Weir. | Boiler Pressure. | Vacuum Gauge. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| Start, | 11·32 | 28156 | Meter not read, as all three Boilers were used. | 4·208 | Temperature not taken. | 69 | 140 | 50· | 20· | |
| | 11·47 | 29129 | | 4·564 | | 69 | 147 | 62· | 21· | |
| | 12·02 | 30233 | | 4·400 | | 69 | 124 | 60· | 22· | |
| | 12·17 | 31284 | | 4·560 | | 69 | 125 | 55· | 21· | |
| | 12·32 | 32237 | | 4·444 | | 69 | 130 | 56· | 22· | |
| | 12·47 | 33262 | | 4·564 | | | 129 | 58· | 22· | |
| Finish, | 1·02 | 34300 | | 4·578 | | 69 | 128 | | 22· | |

## Case I.—Condensing.—Variable Cut-off.

Table No. 1.
Test No. 4.
Date of Test, May 25, 1884, 2·04 P. M. to 4·04 P. M.
Duration of Test, 2 hours.

*Conditions:* Constant Pressure. Constant Speed. Variable Cut off.

| | Time. | Speed Counter. | Water Meter. | Height Over Notch Board. | Temperature Feed Water. | Temperature Injection Water. | Temperature Weir. | Boiler Pressure. | Vacuum Gauge. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| Start, | 2·04 | 34815 | | 4·072 | 114 | 68 | 144 | 61·5 | 22· | Deduct $24\frac{15}{32}$ lbs. |
| | 2·19 | 35845 | | 4·016 | | 68 | 134 | 61· | 22· | |
| | 2·34 | 36842 | | 4·108 | | 67 | 126 | 62· | 22·5 | |
| | 2·49 | 37850 | | 4·009 | | 68 | 132 | 62· | 22· | |
| | 3·04 | 38878 | | 3·996 | | 68 | 128 | 60· | 22· | |
| | 3·19 | 39910 | | 3·996 | | 68 | 128 | 62· | 22· | |
| | 3·34 | 40891 | | 3·952 | | 68 | 129 | 60· | 22· | |
| | 3·49 | 41910 | | 3·964 | | 68 | 130 | 62· | 22· | |
| Finish, | 4·04 | 42910 | | 4·032 | | 67 | 132 | | | |

## Calorimeter Tests.

*Case I.*—Condensing.—Variable Cut-off.

| In Connection with Engine Trial. | Initial Weight. | Initial Weight plus Condensing Water. | Final Weight. | Initial Temperature. | Final Temperature. | Flow in Air. | Flow in Steam. | Boiler Pressure. |
|---|---|---|---|---|---|---|---|---|
| | | | | degrees. | degrees. | minutes. | minutes. | |
| No. 1. | $68\frac{3}{8}$ | $138\frac{3}{8}$ | $143\frac{3}{4}$ | 70 | 144·5 | 1 | $2\frac{1}{2}$ | 60·5 |
| No. 2. | $68\frac{5}{16}$ | $138\frac{5}{16}$ | 144 | 74 | 150· | 1 | $2\frac{1}{2}$ | 65· |
| No. 3. | $68\frac{13}{16}$ | $138\frac{13}{16}$ | $142\frac{61}{64}$ | 84 | 140· | $1\frac{1}{4}$ | 2 | 57· |
| No. 4. | $69\frac{5}{16}$ | $139\frac{5}{16}$ | $148\frac{43}{64}$ | 70 | 132·5 | 1 | 2 | 62· |

## 16. Case II.

The next set of five tests with condenser was made with ratio of expansion and piston speed of engine constant, varying only the pressure of the boiler in the tests of this set.

Starting with an average of eighty pounds in the first test, and concluding with a pressure of 22·3 pounds in the fifth.

Table 2, lines 8 and 11, will show that the conditions of constancy of speed and ratio of expansion were maintained with a sufficient degree of accuracy, so that there can be no doubt but that any difference in the amount of condensation found to have occurred must be due to variation in the initial pressure.

The logs and trials of this set are given below :

Case II.—Condensing.—Variable Boiler Pressure.

Table No. 2.
Test No. 5.
Date of Test, May 26, 1884, 8·01 to 10·1 A. M.
Duration, 2 hours.

*Conditions* : Variable Pressure. Constant Speed. Constant Cut-off.

| | Time. | Speed Counter. | Water Meter. | Height over Notch Board. | Temperature Feed Water. | Temperature Injection Water. | Temperature Weir. | Boiler Pressure. | Vacuum Gauge. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| Start, | 8·01 | 43625 | 5848·7 | 3 740 | | 66 | 101 | 75· | 22 5 | |
| | 8·22 | 44695 | 5863· | 4·020 | 61 | 66 | 110 | 82· | 22· | Deduct 19½ lbs. |
| | 8·37 | 45765 | | 4 020 | | 66 | 108 | 82· | 22·5 | |
| | 8·52 | 46795 | 5883· | 4·020 | 103 | 66 | 110 | 80· | 22·5 | |
| | 9·01 | 47855 | | 4·084 | | 66 | 106 | 80· | 22·5 | Boiler foaming some, 9·15 A.M. |
| | 9·22 | 48845 | | 4·028 | 97 | 66 | 103 | 75· | 22·5 | Deduct 18¾ lbs. |
| | 9·37 | 49887 | 5925· | 3·640 | | 66 | 110 | 83· | 22·5 | |
| | 9·52 | 50945 | 5952·5 | 3·650 | | 66 | 104 | 81· | 22·5 | |
| Finish, | 10.01 | 51907 | 5960. | 3 620 | | 66 | 111 | 82· | 22·5 | |

CASE II.—CONDENSING.—VARIABLE BOILER PRESSURE.

Table No. 2.
Test No. 6.
Date of Test, May 26, 1884, 10·38 A. M. to 12·23 P. M.
Duration, 1¾ hours.

*Conditions:* Variable Pressure. Constant Speed. Constant Cut-off.

| | Time. | Speed Counter. | Water Meter. | Height over Notch Board. | Temperature Feed Water. | Temperature Injection Water. | Temperature Weir. | Boiler Pressure. | Vacuum Gauge. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| Start, | 10·38 | 52610 | 5978· | 4·120 | | 66 | 111 | 65· | 22· | |
| | 10·53 | 53695 | | 3·390 | 102 | 66 | 116 | 65· | 22·25 | |
| | 11·08 | 54765 | 6000· | 3·348 | 102 | 66 | 117 | 67· | 22· | Deduct 12 lbs. |
| | 11·23 | 55840 | | 3·304 | | 66 | 115 | 67· | 23· | |
| | 11·38 | 56865 | 6040· | 3·375 | | 66 | 108 | 69· | 22·5 | |
| | 11·53 | 57895 | 6045 | 3·392 | | 66 | 130 | 66· | 22· | |
| | 12·08 | 58975 | 6057·5 | 3·324 | | 66 | 118 | 69· | 22· | |
| Finish, | 12·23 | 60036 | 6060· | 3·360 | | 66 | 136 | 67· | 22·25 | |

CASE II.—CONDENSING.—VARIABLE BOILER PRESSURE.

Table No. 2.
Test No. 7.
Date of Test, May 26, 1884, 2·54 to 4·54 P. M.
Duration, 2 hours.

*Conditions:* Variable Pressure. Constant Speed. Constant Cut-off.

| | Time. | Speed Counter. | Water Meter. | Height over Notch Board. | Temperature Feed Water. | Temperature Injection Water. | Temperature Weir. | Boiler Pressure. | Vacuum Gauge. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| Start, | 2·54 | 60090 | 6109· | 3·500 | | 68 | 101 | 52· | 22·5 | |
| | 3·09 | 61100 | | 3·632 | 118 | 68 | 104 | 52· | 22·5 | |
| | 3·24 | 62125 | | 3·516 | | 68 | 108 | 54 | 22·5 | |
| | 3·39 | 63230 | 6127· | 3·432 | | 68 | 110 | 52· | 22·5 | Deduct 20 lbs. |
| | 3·54 | 64305 | | 3·424 | | 68 | 109 | 52· | 22· | |
| | 4·09 | 65405 | | 3·280 | | 68 | 112 | 52· | 22·5 | |
| | 4·24 | 66510 | 6152· | 3·320 | 110 | 68 | 118 | 52· | 22·5 | Deduct 9 lbs. |
| | 4·39 | 67585 | 6169· | 3·320 | | 68 | 120 | 52· | 22·5 | |
| Finish, | 4·54 | 68698 | 6179· | 3·315 | | 68 | 122 | 53· | 22·5 | |

## Case II.—Condensing.—Variable Boiler Pressure.

Table No. 2.
Test No. 8.
Date of Test, May 28, 1884, 7·36 to 9·36 A. M.
Duration, 2 Hours.

*Conditions:* Variable Pressure. Constant Speed. Constant Cut-off.

| | Time. | Speed Counter. | Water Meter. | Height Over Notch Board. | Temperature Feed Water. | Temperature Injection Water. | Temperature Weir | Boiler Pressure. | Vacuum Gauge. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| Start, | 7·36 | 69053 | 6515· | 3·300 | | 65 | 102 | 37· | 22· | |
| | 7·51 | 70157 | 6526 | 3·384 | | 65 | 95 | 39· | 22·5 | |
| | 8·06 | 71192 | | 3·020 | | 65 | 99 | 37· | 22·5 | |
| | 8·21 | 72216 | 6540· | 2·988 | | 65 | 99 | 36· | 22·5 | |
| | 8 36 | 73232 | | 2·948 | | 65 | 100 | 37· | 22 75 | |
| | 8·51 | 74250 | 6545· | 3·012 | 128 | 65 | 99 | 37· | 23· | Deduct 20⅝ lbs. |
| | 9·06 | 75274 | | 3·010 | | 64 | 102 | 36· | 23· | |
| | 9·21 | 76299 | 6565· | 2·900 | 96 | 64 | 102 | 38· | 23· | |
| Finish, | 9·36 | 77323 | 6569· | 2·904 | | 64 | 101 | 36· | 23· | Deduct 7 lbs. |

## Case II.—Condensing.—Variable Boiler Pressure.

Table No. 2.
Test No. 9.
Date of Test, May 27, 1884, 10·15 A. M. to 12·27 P. M.
Duration, 2 Hours.

*Conditions:* Variable Pressure. Constant Speed. Constant Cut-off.

| | Time. | Speed Counter. | Water Meter. | Height over Notch Board. | Temperature Feed Water. | Temperature Injection Water. | Tem, eratureWeir. | Boiler Pressure. | Vacuum Gauge. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| Start, | 10·15 | 78302 | 6608·7 | 3 200 | 94 | 64· | 88 | 23· | 23· | Deduct 22 lbs. |
| | 10·30 | 79321 | 6614· | 2·380 | | 64· | 102 | 22· | 23· | |
| | 10·45 | 80342 | | 2·324 | | 64· | 103 | 22· | 23· | |
| | 11·00 | 81363 | | 2·348 | | 64· | 103 | 22·5 | 23· | |
| | 11·15 | 82379 | | 2·404 | | 64· | 102 | 21· | 23· | |
| | 11·30 | 83391 | 6634· | 2·400 | | 64·5 | 110 | 22· | 23· | |
| | 11·36 | Stopped | on acco | unt of ec | centri | c stra | p. St | arted | a gain at | 11·42 A. M. |
| | 11·42 | 83871 | 6642· | 2·400 | 118 | 64·5 | 101 | 26· | 23· | Deduct 15¾ lbs |
| | 11·57 | 84892 | | 2·390 | | 64 5 | 102 | 22 5 | 23· | |
| | 12·12 | 85912 | 6650· | 2 400 | | 64·5 | 101 | 20· | 23· | |
| Finish, | 12·27 | 86935 | 6652·5 | 2·396 | 106 | 64·5 | 104 | 22· | 23· | Deduct 22¾ lbs. |

Calorimeter Tests.

*Case II.*—Condensing.—Variable Boiler Pressure.

| In Connection with Engine Trial. | Initial Weight. | Initial Weight plus Condensing Water | Final Weight. | Initial Temperature. | Final Temperature. | Flow in Air. | Flow in Calorimeter. | Boiler Pressure. |
|---|---|---|---|---|---|---|---|---|
| | | | | degrees. | degrees. | minutes. | minutes. | |
| No. 5. | 69½ | 139½ | 145¼ | 67·5 | 152 | 1 | 2½ | 82· |
| No. 6. | 70 | 140 | 146¼ | 69· | 156 | 1 | 3 | 67·5 |
| No. 7. | 70 9/16 | 140 9/16 | 145 3/16 | 70· | 138 | 1 | 2 | 54· |
| No. 8. | 70⅞ | 140⅞ | 146⅜ | 67·5 | 139 | 1 | 4 | 36·5 |
| No. 9. | 70⅞ | 140⅞ | 146¼ | 67· | 140 | 1 | 6 | 22·5 |

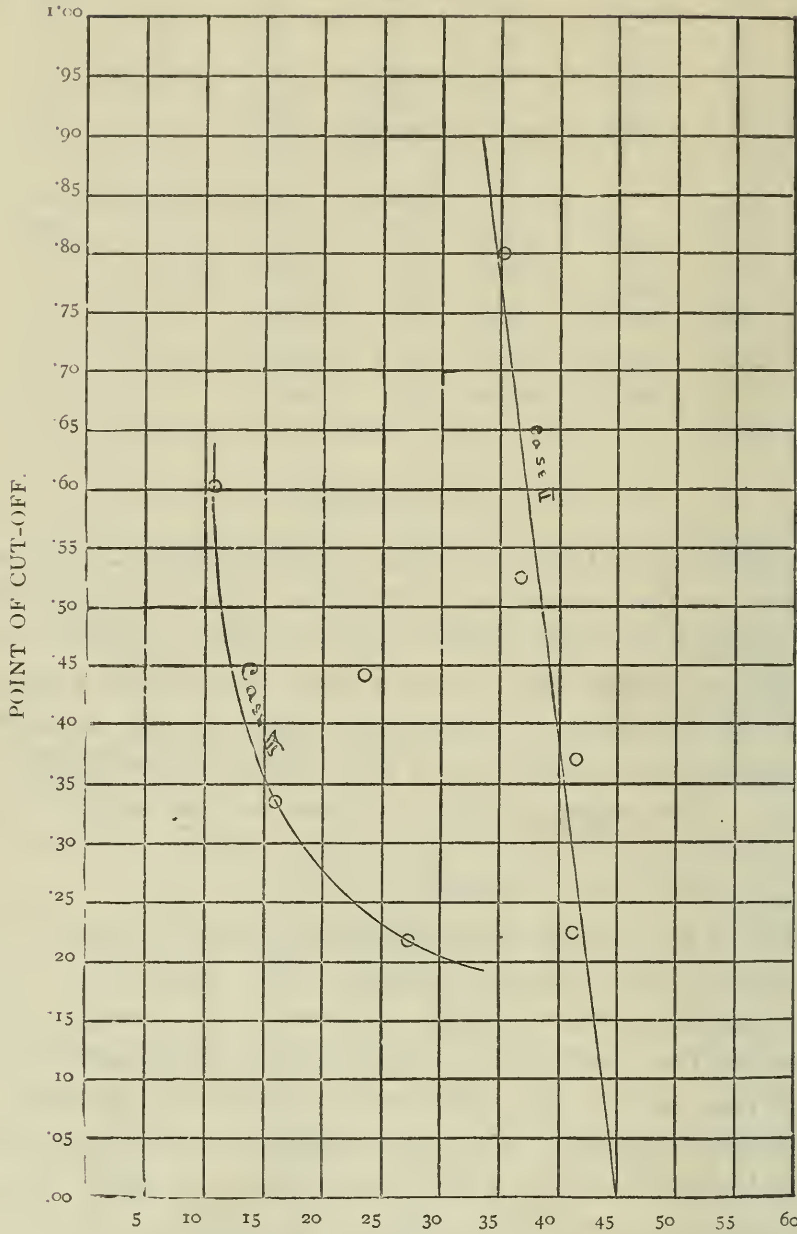
## 17. Case III.

The third set of trials was made supplementary to the second, in as much as the conditions of constant ratio of expansion, and speed of piston were the same, and the boiler pressure variable. The difference being that in the former the engine was worked under "low pressure," or condensing, while in the latter set the condenser was disconnected and the engine worked under "high pressure." The range in initial pressure worked under is not as great in this latter set, the boilers being unable to work higher without the aid of the condenser.

In Test 2 the average pressure under which the test was made was 44·09, and the logs and indicator cards taken show that the proper conditions were rigidly observed. For some reason, in representing the result of this set graphically, the point corresponding with this second trial falls some distance to the right, so a curve passing through it, and the remaining three points, would be so irregular and would so widely differ from that curve representing the preceding set, that it is better disregarded. For, it can be readily understood, that the curve representing each should have the same general appearance, although a difference in the absolute amounts of condensation in the two cases would be expected and are seen to exist. *Plate IV.*

The logs and calorimeter tests made during this set are given below :

PLATE IV.




CONDENSATION WITH VARYING PRESSURE.

### CASE III.—NON-CONDENSING.—VARIABLE BOILER PRESSURE.

Table No. 3.
Test No. 10.
Date of Test, May 27, 1884, 1·50 to 4·50 P. M.
Duration, 3 Hours.

*Conditions:* Variable Pressure. Constant Speed. Constant Cut-off.

| TIME. | Speed Counter. | Water Meter. | Boiler Pressure. | Temperature Feed Water. | REMARKS. | CALORIMETER TEST |
|---|---|---|---|---|---|---|
| Start, | | | | | | |
| 1·50 | 905 | 6688·3 | 20· | 102 | | Initial weight, . . . . . . . . . . . 71⅛ |
| 2·05 | 1915 | 6696· | 22· | 105 | | Initial w'ht + W. lbs. of cond. water, 141⅛ |
| 2·20 | 2909 | 6705·5 | 21· | 110 | | Final weight after introducing steam, 146⅞ |
| 2·35 | 3910 | | 21· | 112 | Deduct 23 3-16 lbs. | Initial temperature, . . . . . . . . 71· ° F. |
| 2·50 | 4905 | | 24· | | | Final temperature, . . . . . . . . 152·5° F. |
| 3·05 | 5901 | | 21·5 | | | Boiler pressure, . . . . . . . . . . . . . 22 |
| 3·20 | 6899 | | 22· | 112 | | Flow of steam in air, . . . . . . . 1 min. |
| 3·35 | 7891 | 6744· | 23·25 | 111 | Deduct 23 3-16 lbs. | Flow of steam in calorimeter, . . . 6 min. |
| 3·50 | 8889 | 6750·5 | 20· | | | |
| 4·05 | 9886 | | 20·5 | 96 | | |
| 4·20 | 10884 | | 23·25 | 94 | | |
| 4·35 | 11881 | | 21·5 | 95 | Deduct 27 4-16 lbs | |
| 4·50 | 12878 | 6779· | 22· | | | |
| Finish | | | | | | |

### CASE III.—NON-CONDENSING.—VARIABLE BOILER PRESSURE.

Table No. 3.
Test No. 11.
Date of Test, May 28, 1884, 7·30 to 10·30 A. M.
Duration, 3 Hours.

*Conditions:* Variable Pressure. Constant Speed. Constant Cut-off.

| TIME. | Speed Counter. | Water Meter. | Boiler Pressure. | Temperature Feed Water. | REMARKS. | CALORIMETER TEST. |
|---|---|---|---|---|---|---|
| Start, | | | | | | |
| 7·30 | 12520 | 6854· | 72· | | | Initial weight, . . . . . . . . . . 71. lbs. |
| 7·45 | 13537 | 6858·5 | 62· | 158 | Deduct 22½ lbs. | Initial w'ht + condensing water, . 141· lbs. |
| 8·00 | 14562 | 6879· | 55· | 116 | | Final weight, . . . . . . . . . . 146¼ " |
| 8·15 | 15585 | 6905· | 59· | 106 | Deduct 23½ lbs. | Initial temperature, . . . . . . . 68· ° F. |
| 8·30 | 16615 | 6908·5 | 61· | 116 | | Final temperature, . . . . . . . 146· ° F. |
| 8·45 | 17624 | 6921· | 62· | | | Boiler pressure, . . . . . . . . . . . . 59 |
| 9·00 | 18656 | 6935· | 51· | 93 | | Steam flowed in air, . . . . . . . . 1 min. |
| 9·15 | 19680 | | 62· | | | Steam flowed in calorimeter, . . . . 3 min. |
| 9·30 | 20685 | 6966· | 59·5 | 104 | Deduct 21¼ lbs. | |
| 9·45 | 21701 | 6980· | 60· | 140 | | |
| 10·00 | 22716 | 6991· | 61· | 98 | | |
| 10·10 | 23738 | 7014· | 56·5 | | | |
| 10·30 | 24757 | 7037· | 61· | 84 | Deduct 23⅜ lbs. | |
| Finish | | | | | | |

## Case III.—Non-Condensing.—Variable Boiler Pressure.

Table No. 3.
Test No. 12.
Date of Test, May 28, 1884, 11·08 A. M. to 1·38 P. M.
Duration, 2½ Hours.

*Conditions :* Variable Pressure. Constant Speed. Constant Cut-off.

| E | Speed Counter. | Water Meter. | Boiler Pressure. | Temperature Feed Water. | Remarks. | Calorimeter Test. | |
|---|---|---|---|---|---|---|---|
| Start, | | | | | | | |
| 11·08 | 25345 | 7078·2 | 44· | | | | |
| 11·23 | 26410 | 7086· | 43· | 94 | Deduct 23⅛ lbs. | Initial weight, . . . . . . . . | 71 1-16 lbs. |
| 11·38 | 27417 | 7102· | 45· | 98 | | Initial weight + cond. water, . | 141 1-16 lbs. |
| 11·53 | 28448 | 7113· | 43· | 98 | | Final weight, . . . . . . . . . | 146 1-16 lbs. |
| 12·08 | 29510 | 7126· | 44· | 98 | | Initial temperature, . . . . . . . | 65° F. |
| 12·23 | 30557 | 7142· | 44· | 98 | | Final temperature, . . . . . . . . . | 137° F. |
| 12·38 | 31583 | 7150· | 43· | 86 | | Boiler pressure, . . . . . . . . . | 43·5 |
| 12·53 | 32586 | 7169· | 45· | 94 | | Flow in air, . . . . . . . . . . . . | 1 min. |
| 1·08 | 33604 | 7178· | 44· | 100 | Deduct 25½ lbs. | Flow in calorimeter, . . . . . . . | 5 min. |
| 1·23 | 34627 | 7193· | 44·5 | 100 | | | |
| 1·38 | 35631 | 7215· | 45·5 | 88 | Deduct 16 lbs. | | |
| Finish | | | | | | | |

## Case III.—Non-Condensing.—Variable Boiler Pressure.

Table No. 3.
Test No. 13.
Date of Test, May 28, 1884, 2·19 to 5·19 P. M.
Duration, 3 Hours.

*Conditions :* Variable Pressure. Constant Speed. Constant Cut-off.

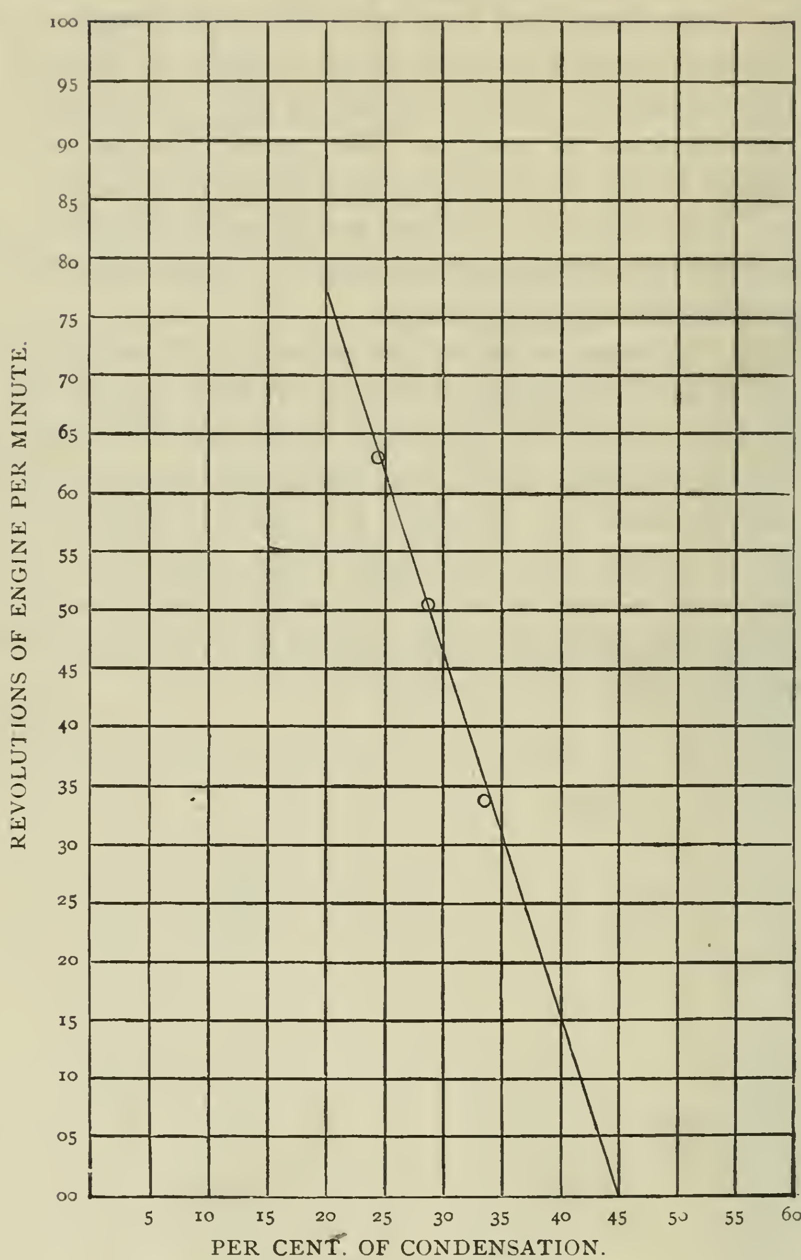
| Time | Speed Counter. | Water Meter. | Boiler Pressure. | Temperature Feed Water. | Remarks. | Calorimeter Test. | | |
|---|---|---|---|---|---|---|---|---|
| Start, | | | | | | | | |
| 2·19 | 36204 | 7224· | 32· | | | | 1st. | 2d. |
| 2·34 | 37198 | 7233· | 34·5 | 100 | | Initial weight, . . . . . | 71¼ | 71 9-16 |
| 2·49 | 38207 | 7242· | 35· | 106 | | In. weight + cond. water, | 141¼ | 141 9-16 |
| 3·04 | 39225 | 7252· | 34·5 | 110 | | Final weight, . . . . | 148 11-16 | 148 |
| 3·19 | 40253 | 7265· | 33·5 | 86 | Deduct 18 lbs. | Initial temperature, . . | 60·5° F. | 60.5° F. |
| 3·34 | 41265 | 7270· | 33· | 88 | | Final temperature, . . . | 160·5° F. | 150.5° F. |
| 3·49 | 42280 | 7292· | 32·5 | 102 | | Boiler pressure, . . . . | 33·5 | 33· |
| 4·04 | 43294 | | 34· | | | Flow in air, . . . . . . . | 1 min. | 1 min. |
| 4·19 | 44300 | 7303· | 32· | 102 | Deduct 20 3-10 lbs. | Flow in calorimeter, . . | 5½ min. | 5 min. |
| 4·34 | 45311 | 7313· | 32·5 | 105 | | | | |
| 4·49 | 46325 | 7322· | 34· | 104 | | | | |
| 5·04 | 47325 | 7331· | 34·5 | 90 | | | | |
| 5·19 | 48357 | 7343·5 | 33·5 | 95 | Deduct 24⅝ lbs. | | | |
| Finish | | | | | | | | |

## 18. Case IV.

The fourth and last set made were to determine the effect caused by different speed of engine or time of exposure of the initial surface of the cylinder. Starting with an average boiler pressure of 19·67 pounds and a cut-off of ·98 of the length of stroke and the engine running at an average of 33·74 revolutions per minute, three trials were made, concluding with an average speed of 62·977 revolutions per minute. The greatest variation in the point of cut-off being ·05 of the stroke, and in the pressure ·63 of a pound. Any difference in the condensative found to have occurred in the three trials can therefore be attributed strictly to the range of speed worked through.

Difficulty was found in getting the engine to run smoothly lower than thirty-three revolutions per minute, and the opportunity was wanting to make a fourth test at a higher speed than sixty-three revolutions, the engine being needed on the regular work of the mill. But it will be seen by reference to *Plate V* that the three points of the curve given by these three trials are so nearly in line that a fourth test is hardly necessary in order to find the law governing the variation. All the data taken during the three trials are given below in tabular form:

PLATE V.




CONDENSATION WITH ENGINE-SPEED VARIABLE.

CASE IV.—CONDENSING.—VARIABLE REVOLUTIONS.

Table No. 4.
Test No. 14.
Date of Test, May 29, 1884, 7·57 to 9·42 A. M.
Duration, 1¾ hours.

*Conditions:* Variable Speed. Constant Cut-off. Constant Pressure.

| | Time. | Speed Counter. | Water Meter. | Height over Notch Board. | Temperature Feed Water. | Temperature Injection Water. | Temperature Weir. | Boiler Pressure. | Vacuum Gauge. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| Start, | 7·57 | 1182 | 7380· | 1·900 | | 53· | 130 | 21· | 20· | |
| | 8·07 | 1497 | 7404·5 | 2·280 | 166 | 53· | 135 | 21· | 20· | |
| | 8·17 | 1768 | | 2·212 | | 52·5 | 123 | 19· | 20· | |
| | 8·27 | 2121 | 7405· | 2·282 | 110 | 53· | 138 | 19· | 20· | |
| | 8·37 | 2478 | | 2·280 | | 53· | 134 | 20· | 20· | |
| | 8·47 | 2819 | | 2.288 | | 53· | 130 | 19·5 | 20· | |
| | 8·57 | 3162 | | 2·3 | | 52· | 137 | 19· | 20· | |
| | 9·07 | 3532 | | 2·298 | 100 | 52· | 137 | 20· | 20· | $23\frac{3}{16}$ lbs. out. |
| | 9·17 | 3880 | 7438 2 | 2·290 | | 52·5 | 132 | 19·5 | 20· | |
| | 9·27 | 4215 | | 2·256 | | 52· | 131 | 19· | 20· | |
| | 9·37 | 4556 | | 2·308 | 80 | 52· | 134 | 20· | 20· | |
| Finish, | 9·42 | 4725 | 7446·5 | 2·312 | | 52· | 128 | 19· | 20· | Deduct 7 lbs. |

CASE IV.—CONDENSING.—VARIABLE REVOLUTIONS.

Table No. 4.
Test No. 15.
Date of Test, May 29, 1884, 9·47 to 11·47 A. M.
Duration, 2 Hours.

*Conditions:* Variable Speed. Constant Cut-off. Constant Pressure.

| | TIME. | Speed Counter. | Water Meter. | Height over Notch Board. | Temperature Feed Water. | Temperature Injection Water. | Temperature Weir. | Boiler Pressure. | Vacuum Gauge. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| Start. | 9·47 | 4949 | 7446·5 | 2·780 | | 52· | 129 | 18·5 | 21·5 | |
| | 9·57 | 5431 | 7452· | 2·774 | 90 | 52·5 | 130 | 19· | 22· | |
| | 10·07 | 5927 | | 2·712 | | 52·5 | 135 | 18·5 | 21·5 | |
| | 10·17 | 6437 | 7466· | 2·718 | | 52·5 | 136 | 20·5 | 21· | |
| | 10·27 | 6925 | | 3·040 | 110 | 52·5 | 120 | 19·5 | 22·5 | Deduct 18 lbs. |
| | 10·37 | 7421 | 7470· | 3·100 | | 52·5 | 120 | 19· | 22·5 | |
| | 10·47 | 7927· | | 3·106 | | 52·5 | 117 | 16· | 23· | |
| | 11·07 | 8975 | | 3·036 | | 53· | 122 | 19· | 22·5 | |
| | 11·17 | 9496 | 7507· | 3·085 | 90 | 52·5 | 119 | 18· | 22·5 | |
| | 11·27 | 9990 | 7514· | 3 085 | | 52·5 | 123 | 20· | 22·5 | |
| | 11·37 | 10495 | 7520· | 3·085 | | 52·5 | 120 | 19·5 | 22·5 | Deduct $17\frac{13}{16}$ lbs. |
| Finish, | 11·47 | 10985 | 7543 | 3·085 | 80 | 53· | 123 | 21· | 22·5 | |

## Case IV.—Condensing.—Variable Revolutions.

Table No. 4.
Test No. 16.
Date of Test, May 29, 1884, 3·00 to 4·30 P. M.
Duration, 1½ Hours.

*Conditions:* Variable Speed. Constant Cut-off. Constant Pressure.

| | Time. | Speed Counter. | Water Meter. | Height over Notch Board. | Temperature Feed Water. | Temperature Injection Water | Temperature Weir | Boiler Pressure | Vacuum Gauge. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| Start, | 3·00 | 18886 | 7655·5 | 4·154 | 98 | 55 | 105 | 24· | 24· | |
| | 3·10 | 19491 | 7668· | 4·100 | | 54 | 104 | 21· | 23·5 | |
| | 3·20 | 20059 | 7672· | 4·200 | 104 | 54 | 104 | 20·5 | 23 5 | |
| | 3·30 | 20639 | | 4·140 | 100 | 54 | 103 | 20· | 23·5 | |
| | 3·40 | 21248 | | 4·040 | 86 | 54 | 107 | 17·5 | 23·5 | Deduct 20¼ lbs. |
| | 3·50 | 21925 | | 4·200 | | 54 | 107 | 18· | 23·75 | |
| | 4 00 | 22597 | | 4·168 | | 54 | 102 | 17·5 | 23·5 | |
| | 4·10 | 23257 | | 4·100 | 103 | 54 | 108 | 17· | 23·75 | |
| | 4·20 | 23911 | | 4·262 | | 54 | 101 | 16· | 23·5 | |
| Finish, | 4·30 | 24554 | 7740· | 4·080 | | 54 | 112 | 19· | 23·75 | Deduct 5 lbs. |

## Condensing Tests.

*Case IV.*—Calorimeter Trials.—Variable Revolutions.

| In Connection with Engine Trial. | Initial Weight. | Initial Weight plus Condensing Water. | Final Weight. | Initial Temperature. | Final Temperature. | Flow in Air. | Flow in Calorimeter. | Boiler Pressure. |
|---|---|---|---|---|---|---|---|---|
| | | | | degrees. | degrees. | minutes. | minutes. | |
| No. 14. | 71 7/16 | 141 7/16 | 148 1/16 | 55· | 145·5 | 1 | 7 | 20· |
| No. 15. | 71⅝ | 141⅝ | 147 15/16 | 55·5 | 142·5 | 1 | 7 | 20·5 |
| No. 16. | 71¾ | 141¾ | 145⅝ | 55·75 | 113· | 1 | 5 | 145· |

(*To be Continued.*)

# RECENT IMPROVEMENTS IN THE MANUFACTURE OF STEEL.*

It may be of interest to the readers of THE JOURNAL to have more definite knowledge, than they can gather from newspapers, of the new processes which are being introduced for the manufacture of steel.

The depressed condition of the iron and steel trade has stimulated inventors and manufacturers to renewed efforts to lessen the cost of production, and the result of these efforts is a number of new processes that have recently been developed, alike in principle, but differing materially in practical application.

The four processes that are exciting the most attention, are the Clapp-Griffiths, the Davy, the Gordon and the Avesta.

They are all based on the pneumatic or Bessemer process, and differ only in the manner of using or applying the blast or tuyeres. The most important and well-developed of the above processes is the Clapp-Griffiths, and the first plant built in this country, at the works of Messrs. Oliver Brothers & Phillips, has been in successful operation for the last six months.

Notwithstanding the unfavorable comments that have been passed upon this process by some of the metallurgical savants of the day, I look upon it as the beginning of a successful revolution against the primitive and barbarous method of puddling, and as inaugurating the most important epoch in the history of iron since the advent of the Bessemer process. It is interesting and instructive to think that the aim of the Clapp-Griffiths process is to accomplish exactly the same result that Bessemer attempted thirty years ago, or in 1855. Bessemer's idea, and the one that came very near wrecking him and thus depriving the world for a

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* To make a complete *résumé* of the subject, Mr. Salom, by request, has elaborated the details of a number of the more prominent modern processes of steel manufacture, which could only be incidentally referred to in his lecture. The same is here introduced as supplementary to his lecture on "The Metallurgy of Steel," published in the September issue of THE JOURNAL.—[Committee on Publication.]

time at least of his invaluable discovery, was to produce cast wrought iron. It is true that Bessemer expected to produce all grades of cast steel, from the hardest tool steel to the softest open-hearth boiler plate, by interrupting the operation at different stages of decarbonization. This expectation was not realized (although it bids fair to be in the future) owing to the presence of silicon and

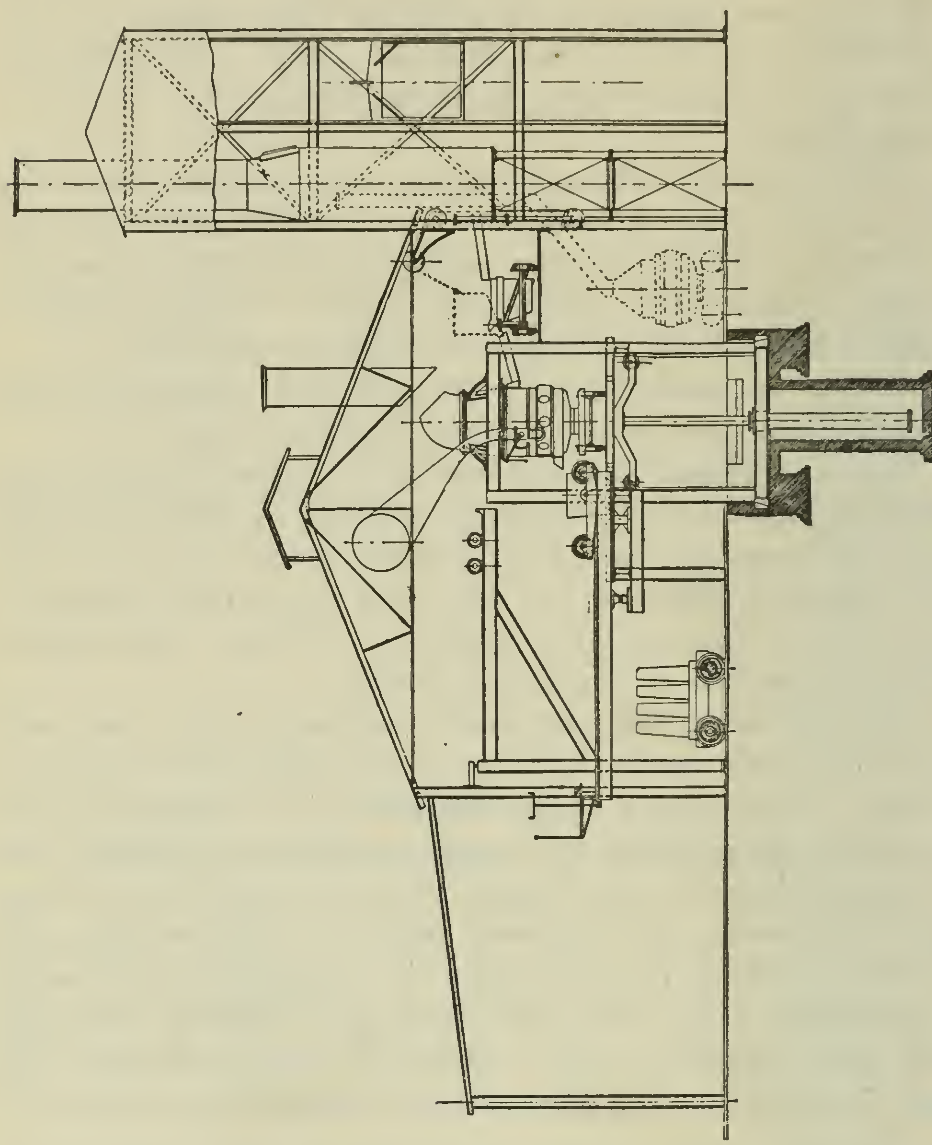
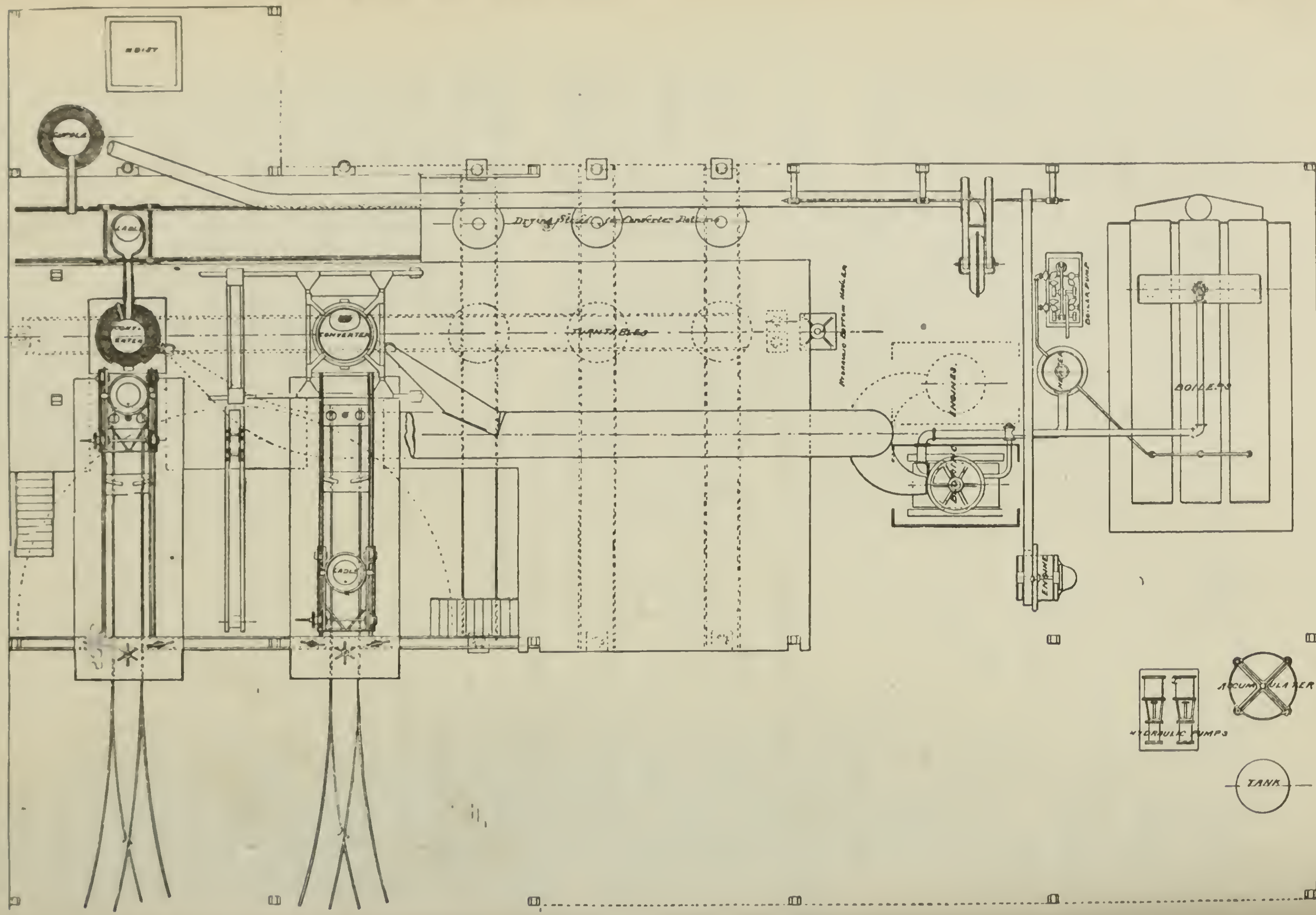


PLATE I.—Clapp-Griffiths Process. (Section of works.)

phosphorus, with the injurious action of which he was not fully acquainted, until some years later. The introduction of spiegel was only an after-thought, or rather an after-necessity, which saved the whole process from total wreck and annihilation.

Through the kindness of Colonel J. P. Witherow, of Pittsburgh,


HOIST
CONVERTER
TURNTABLES
HYDRAULIC BOTTOM HOLDER
ENGINES
BOILER PUMP
HEATER
BOILERS
ENGINE
HYDRAULIC PUMPS
ACCUMULATER
TANK

who, with the Messrs. Oliver, controls the patents for this country, I am able to give the readers of THE JOURNAL some idea of the converter and general arrangements for a Clapp-Griffiths plant.

*Plates I, II* and *III* represent a section, plan and elevation, respectively, of the works. They contain two three-ton converters, back of which is a cupola with a stock hoist. This cupola discharges its contents into an intermediate weighing ladle (shown in the section and in the plan), which travels along a track parallel to the row of converters The converters themselves are hung in a wrought iron frame-work, making the working platform about ten feet above the general level. The bottoms are handled by means of a carriage. When a bottom is defective, the hydraulic hoist, shown in the section, is run up with the carriage upon it, the bottom is loosened, the blast connection broken, and the whole is lowered to the ground floor. * * * A new bottom, previously prepared, is then taken from the drying-stove nearest the converters, run out upon the turn-table opposite, and placed upon the hoist, which is then lifted and the bottom fastened into place, the joints made and operations resumed.

In front of each converter is a peculiar swinging track, arranged for conveniently tapping from the steel ladle into the ingot molds, which stand upon a truck below. The blast for the cupola is furnished by a Sturtevant blower, operated by a small vertical engine placed nearest the hydraulic pumps. A larger engine, with 16-inch steam cylinder, 48-inch blowing cylinder, and 30-inch stroke, furnishes the blast for the converters.

It is estimated that this plant, with two cupolas, will have a daily capacity of 150 tons of ingots in twenty-four hours.

*Plates IV* and *V* represent the fixed bottom converter, similar in design and construction to those at the Margrin Works, Wales, and a number of other works in England. *A* is the main windp pe, carrying blast for the tuyeres, and controlled by a large valve. *B* is a subsidiary pipe, carrying the same pressure of blast, leading into the chamber *G*, containing a differential piston. *C* is the charging-hole; *D*, the cinder-notch or slag-top, and *E*, the tapping-hole. *F* is the main wind-box, into which the blast from the pipe *A* is conveyed, and from whence it passes through the tuyeres *O* into the converter. *G* is the differential piston cylinder; *H*, the differential piston; *K*, the stopper; *L*, the stopper-rod

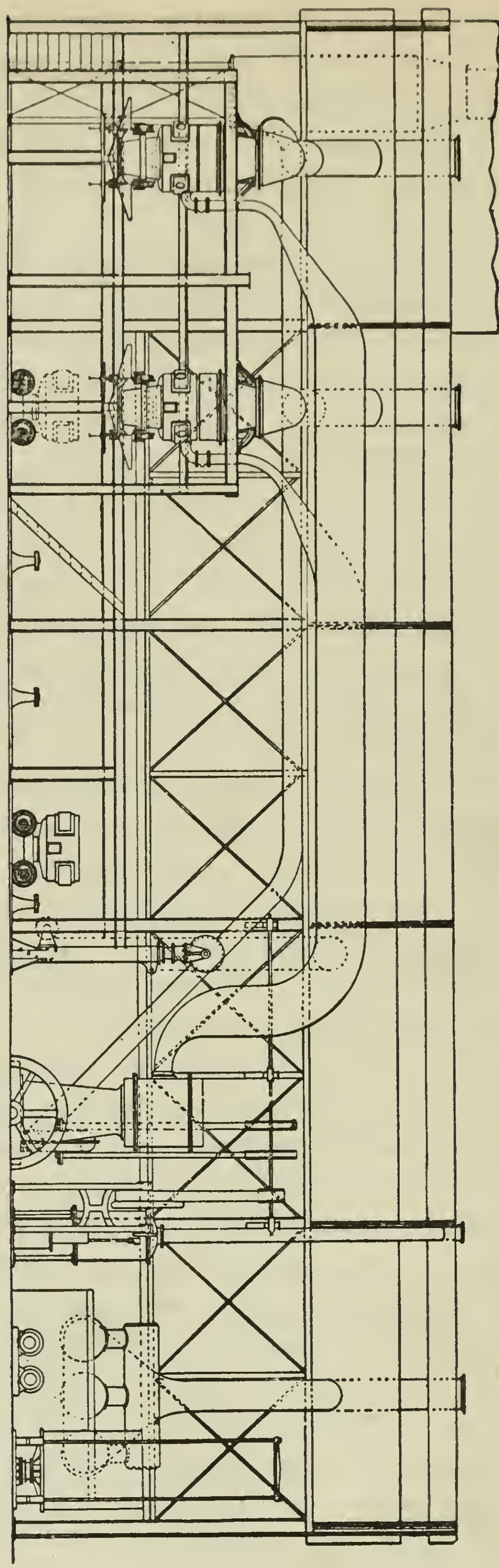


Plate III.—Clapp-Griffiths Process. (Elevation of works.)

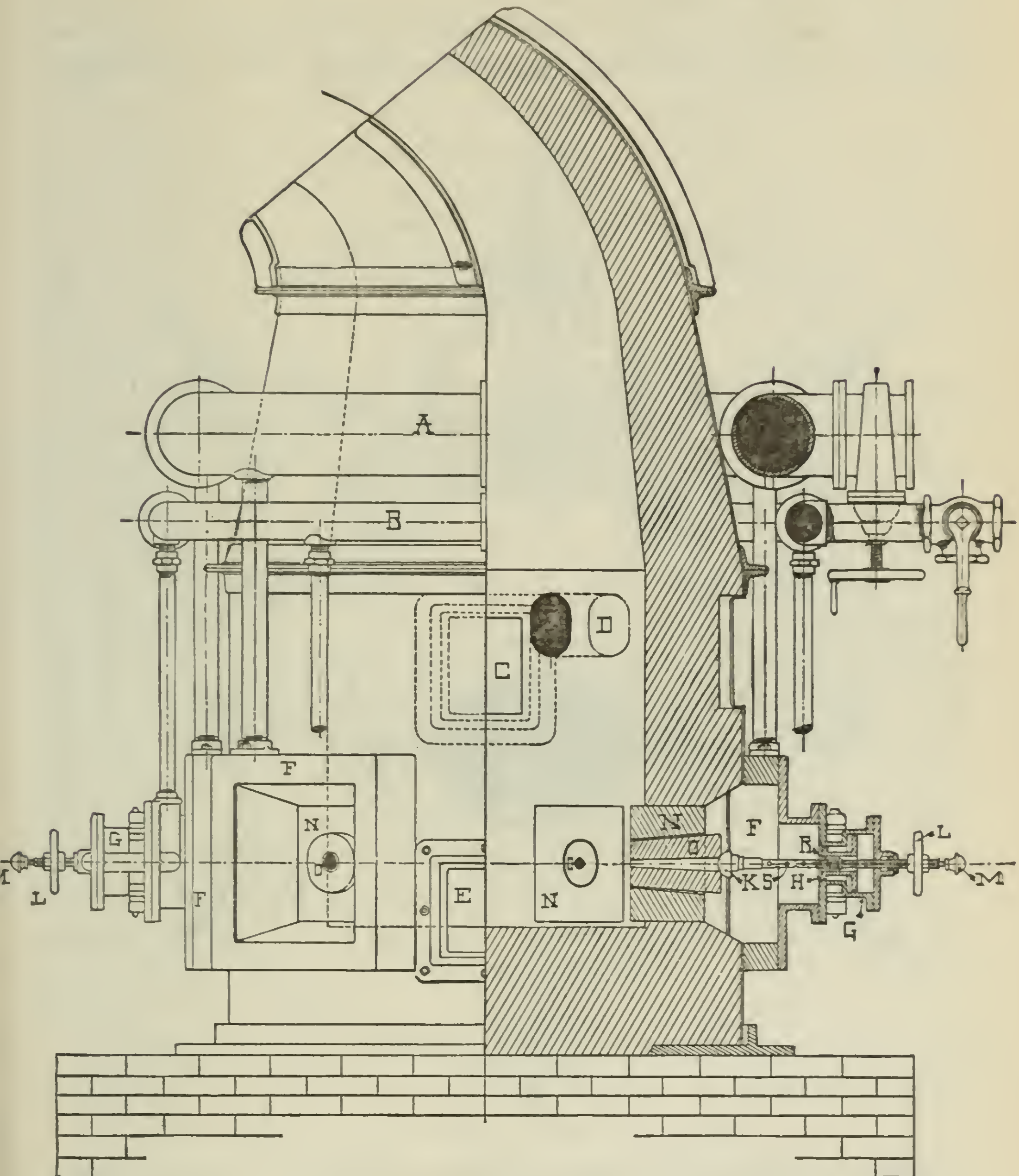



PLATE IV.—Clapp-Griffiths Process. (Elevation of fixed-bottom converter.)

hand wheel; *M*, peep-hole cap; *N*, the tuyere block, and *O*, the tuyeres. *P* is a passage from down-take from the pipe *B* to the back of the differential piston *H*. *R* is the stopper-rod adjusting screw, and *S* the stopper-rod.

The automatic closing of the tuyeres is effected thus: At the moment the blow is finished, the valve leading to the secondary

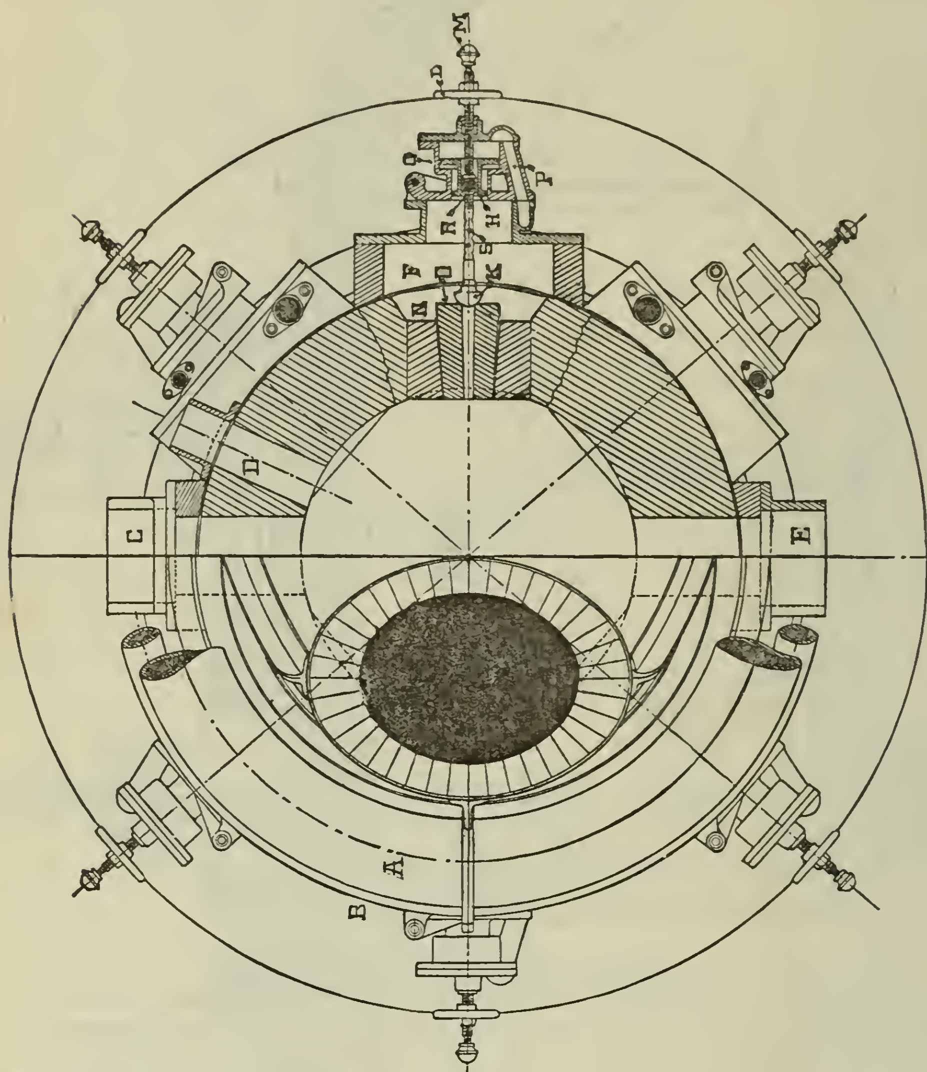



PLATE V.—Clapp-Griffiths Process. (Plan of fixed-bottom converter.)

pipe *B* is opened fully, driving the blast through the passageway *P* (shown on plan) into the cylinder *G* behind the larger end of the piston *H*. The pressure of blast being the same in the cylinder *G* as in the wind-box *F*, as the piston is double faced, having one end of considerably larger diameter than the other, the same pressure of blast per square inch, introduced into the chamber *G*, forces the

piston and stopper rod against the end of the tuyere *O*, closing the hole therein except for a small aperture in the stopper *K*, fed by the holes shown through the hollow stem *S*. This small amount of blast suffices to keep the molten metal from running back into the tuyeres, keeping them free and open. The metal is then tapped out. This operation is simply reversed when the molten metal has been poured into the converter, the blast remaining on in the main-pipe *A* as long as operations are continued. As soon as the molten metal has reached a sufficient depth, and the blow is to begin, the valve of the pipe *B* is closed, the pressure removed from the blast end of the differential piston *H*, and the effect of the blast in the wind-box *F* is to drive the piston *H* out, driving back the stopper.

In the new converters, *Plates VI* and *VII*, with removable bottoms, this arrangement was found undesirable. No pipes whatever corresponding to the pipes *A* and *B* of the old converters are used. The blast is simply led into an annular chamber or wind box surrounding the bottom of the converter, except for a short distance on the front side, to allow room for the tapping hole. The blast at the end of the blow is not entirely cut off, but its pressure is regulated and reduced by any one of several patented devices, which makes it possible to keep a uniform pressure at the noses of all the tuyeres, thus accomplishing the same purpose as the differential piston and stopper of the old converter, viz., to keep the tuyeres free from molten metal or slag. In practice, it is found that this works with perfect certainty.

The lining of the converter is gannister, twelve inches thick, the centres of the tuyeres are nine inches above the bottom of the converter, and the depth of metal above the centre of the tuyeres is eight to ten inches above the bottom of the converter.*

The Clapp-Griffiths process has succeeded in a measure in overcoming the difficulties that Bessemer experienced, in several ways.

(1.) By a different construction of the converter.

(2.) By the introduction of ferro-manganese instead of spiegel.

(3.) By a partial removal of the slag.

(4.) By the introduction of what might be termed a new principle, viz., the change in position and character of the tuyeres,

*Abridged from Hunt's paper on "The Clapp-Griffiths Process." Trans. Am. Inst. Mining Engineers. Vol. XIII.

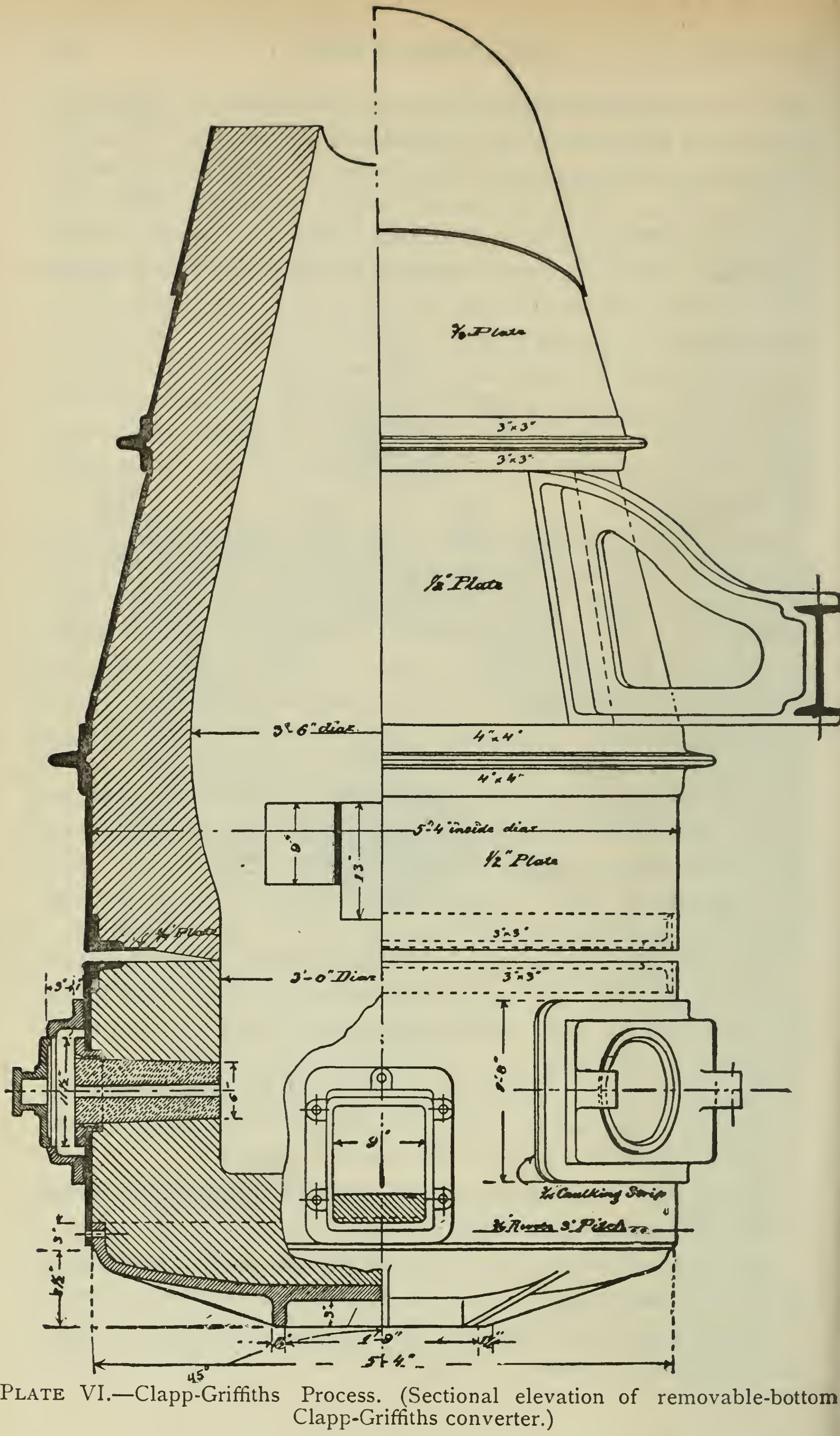



PLATE VI.—Clapp-Griffiths Process. (Sectional elevation of removable-bottom Clapp-Griffiths converter.)

involving as it does a different chemical reaction in the converter.

It will not do, therefore, for the Bessemer men to sneer at their little antagonist. The facts remain that the Bessemer men have been so busy making rails that they have never done anything towards the solution of the problem of avoiding puddling. It has only been within the last few years, that the demand for rails falling short of

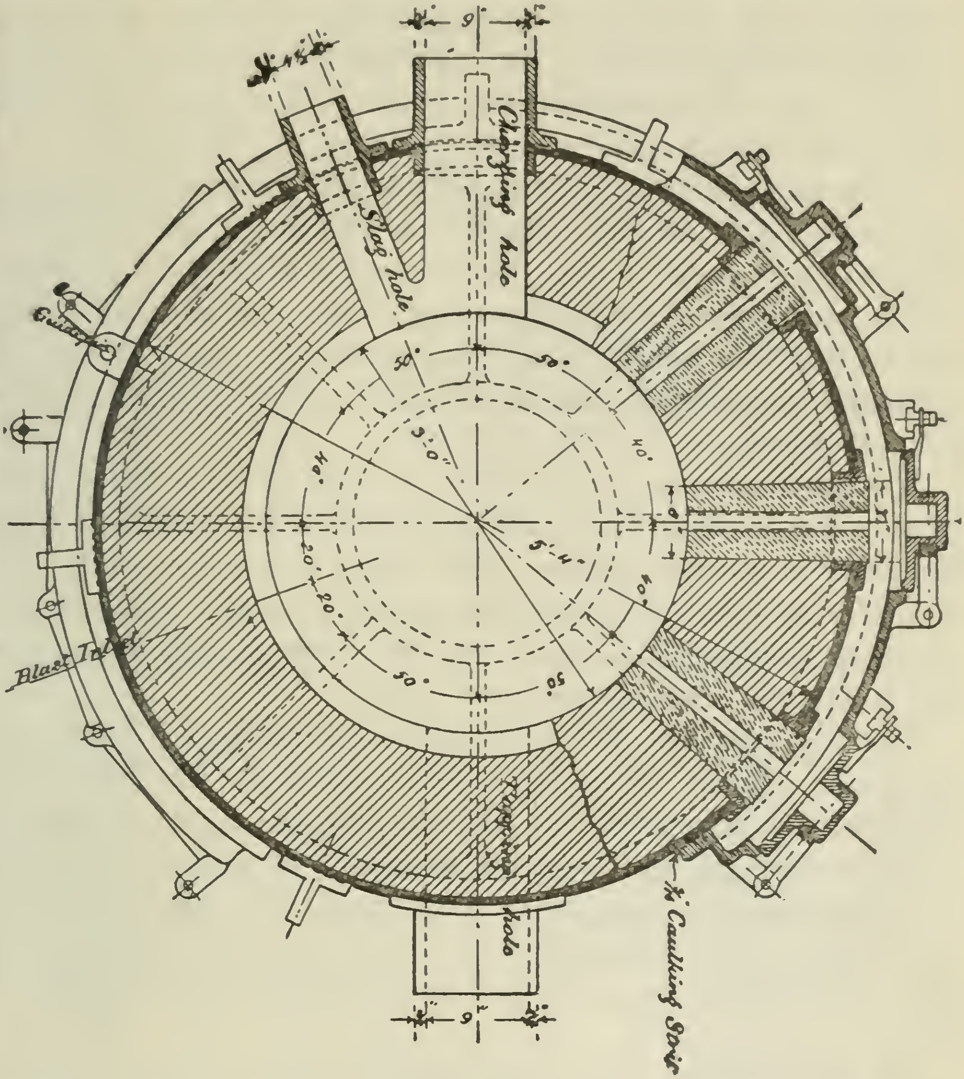



PLATE VII.—Clapp-Griffiths Process. (Section of removable-bottom converter.)

the possible products of the Bessemer mills, they have endeavored, to some extent, to increase the quality of their product, so as to successfully compete with open-hearth steel and charcoal iron. The result of these attempts has not been altogether satisfactory, but enough has been done to show that the highest qualities that steel possesses can sometimes be obtained by the Bessemer process, and it only needs a more careful study of the conditions, both

physical and chemical, under which this material is obtained to be able to produce it with gratifying regularity.

I believe, however, that these results can be more easily obtained in working on a smaller amount of metal than is customary in a Bessemer works.

While the results thus far published do not show that high phosphorus pig can be converted into the best iron, a result which we have no right to expect, they do show that steel with twenty-four per cent. elongation, almost equal to the best open-hearth boiler plate, can be made with 0·3 per cent. of phosphorus.

We must remember, likewise, that puddled iron made from high phosphorus pig has no ductility or elongation and breaks off about as short as pig iron. Moreover, the tests show that steel with 0·5 per cent. of phosphorus has been made with an elongation of nine per cent. This is an admirable result and it only remains to accomplish the same result every time, to insure a complete success.

The announcement of the Davy process created no little excitement in the metallurgical world, and especially in Sheffield, where Mr. Davy is so well known. The Davy converter, (*Plate VIII*) or, rather process (for he does not employ a regular converter simply using the foundry ladle for the converting vessel) is so simple, that it may be described in a few words.

Into the foundry ladle, which stands on the floor, he introduces a straight pipe or tuyere, to which is attached the ladle cover. The tuyere is connected with the blowing apparatus, and may be raised or lowered into the ladle, by means of an hydraulic crane, or the pipe and lid may be stationary, and the ladle raised until the tuyere is below the surface of the metal. An opening on one side of the cover allows the hot gases, made during the blow, to escape.

Mr. Davy makes some extraordinary claims for his apparatus. He claims to be able to make steel with 80,000 pounds tensile strength, and twenty per cent. elongation; that such steel will not cost more than from $20 to $22 per ton, taking pig iron at $15; and that the cost of the apparatus for producing one ton at a time would only be $3,000 complete.

The almost ridiculous simplicity of the Davy process is a strong argument in its favor. The possibility of being able to make all

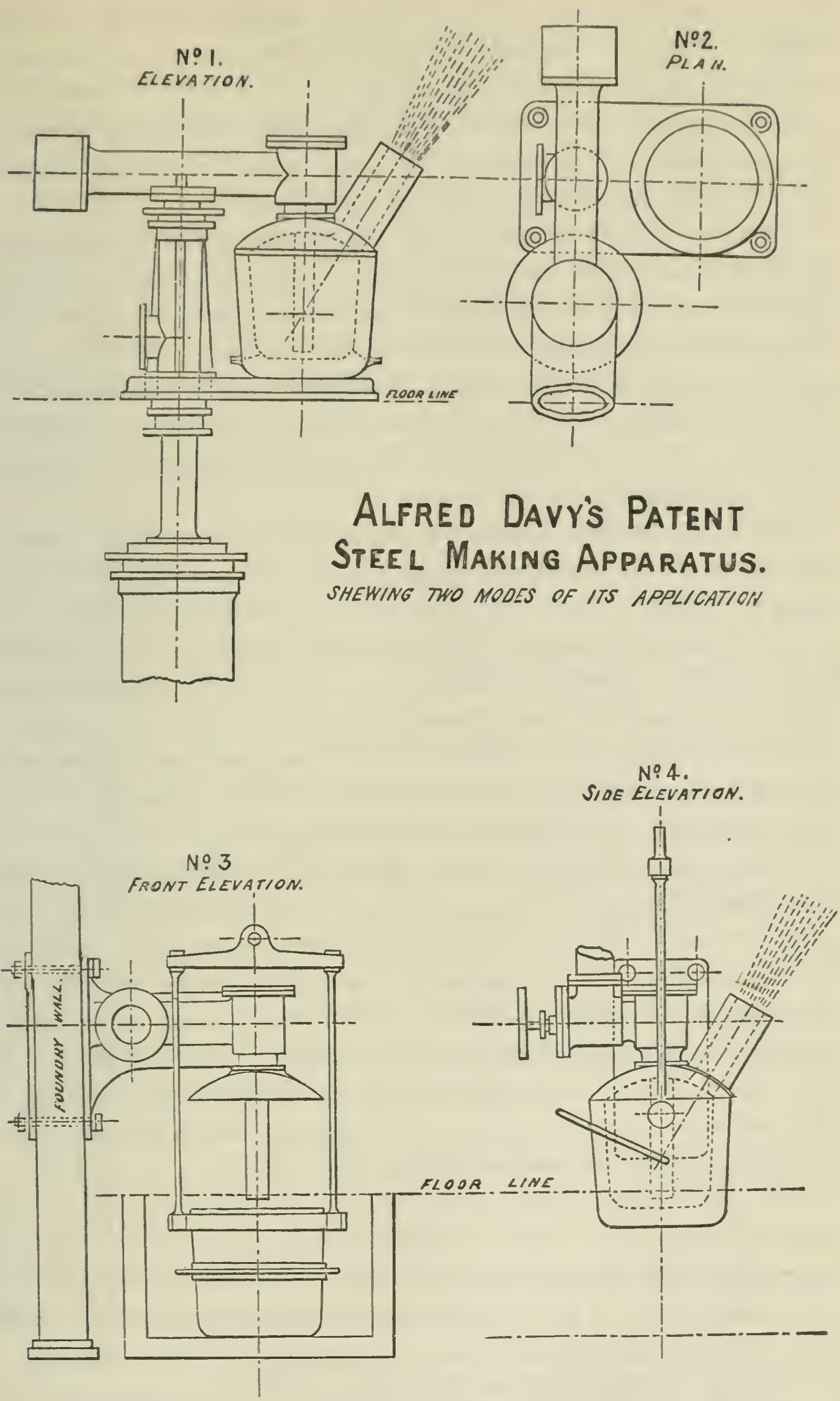

No. 1.
ELEVATION.
No. 2.
PLAN.
FLOOR LINE
ALFRED DAVY'S PATENT
STEEL MAKING APPARATUS.
SHEWING TWO MODES OF ITS APPLICATION
No. 4.
SIDE ELEVATION.
No. 3
FRONT ELEVATION.
FOUNDRY WALL.
FLOOR LINE

PLATE VIII.

kinds of steel in an ordinary foundry ladle, with only ordinary foundry appliances, seems almost as chimerical as the Bessemer process itself seemed thirty years ago.

I believe, however, that in practice it will be found that no end of trouble will be experienced in protecting the tuyere from the almost irresistible action of the escaping gases.

The Davy process has now been prominently before the public for nearly two years, and although a number of large concerns in England are said to have erected plants, we have not as yet heard of any favorable results achieved by this method. In this country the process has not as yet been tried, and a plant recently started in Ohio, is said to have been abandoned on account of injunctions obtained by Mr. Jacob Reese, of Pittsburg, disputing the validity of the Davy patents.

Mr. R. F. Mushet, writing in the *Engineer*, on "Improvements and Economy in the Production of Bessemer and Mushet Steel," states: "Lately a great and important improvement in the *modus operandi* has been patented by Mr. Alfred Davy, C. E., of Messrs. Davy Brothers, Sheffield, England. The details are most simple, and the mechanical arrangements do great credit to the inventor, who deserves success. Of course, it will be necessary to use suitable pig irons, such as those smelted from red hematite, Elba or Bilboa ores, but this is just as much a *sine qua non* in the ordinary acid Bessemer process. Taken altogether, Mr. Davy's patent arrangement appears to combine facility of production with very great economy and convenience in the necessary plant. I think his arrangement or a similar one is much needed in Sheffield, where alloys of Scotch pig iron and scrap are made into castings by certain enterprising parties, and vended as crucible steel castings, with a tensile strength of only about eight tons per square inch, and very, very far inferior for standing wear and tear, and in strength, to good, honest anthracite pig iron."

*The Mechanical World*, of February 7, 1884, writing on the same subject, says: "We mentioned last week in our Sheffield trade notes that Messrs. Davy Brothers, limited, of Park Works, were introducing a new steel-making apparatus, patented by Mr. Alfred Davy. In principle, this new method of steel making is, we understand, similar to the Bessemer, a blast of air being blown into and thus used to decarbonize and purify molten cast iron.

"The mode and means of applying the blast is, however, altogether different, and, indeed, much simpler under many circumstances, and more general in its application. The converter is like an ordinary foundry ladle, covered by a lid, which has a short spout projecting from its side. The tuyere of the blast pipe projects vertically downwards into the charge, passing through the lid, and approaching the bottom of the ladle. When the blast is turned on the gaseous products are driven out at the spout, the action being similar to that in the Bessemer converter. But the great advantage in Mr. Davy's system is that the converters or ladles are perfectly independent of the blast pipe connections, and can easily be taken with either a large or small charge at any time, and placed under the blast nozzle, being raised by hydraulic power or otherwise, or the nozzle lowered until the latter is inserted to the required depth in the charge. It does not therefore require extensive plant to make steel, and it is not necessary to be making it continuously as with the ordinary Bessemer plant. We understand Mr. Davy has several modifications of the system, more or less on the above lines. In practice and over an extended trial, it is stated to have given very good results, and certainly there appears no reason why it should not do so. If Mr. Davy opens up to iron founders a means of making either steel or iron castings with little more than iron founding plant, he will confer a benefit on the engineering profession. Perhaps he can also show the users of his patents how to make sound steel castings. If so, much will have been done, for those much-to-be-desired articles are yet a rarity even in the most advanced establishments."

The third recent improvement attracting attention, is the Gordon converter. The special features of this converter are due to Mr. F. W. Gordon, of Philadelphia.*

He claims for his converter:

(1.) Intensity of chemical action removed from the lining insuring its durability.

(2.) Ready replacing of tuyeres.

(3.) Withdrawing tuyeres instantaneously and simultaneously, without complications of construction.

(4.) Mild blast, avoiding expensive blowing machinery.

* I am indebted to Mr. Fred. W. Gordon, of Philadelphia, for the cuts representing his converter, and also for the explanation of the same. P. G. S.

(5.) Reduction of carbon and silicon to any desired extent, even to totality.

(6.) Ready access for repairs to every part.

(7.) Low cost of construction and maintenance.

(8.) Production of the best steel from high grade pig irons.

(9.) Bessemer steel from ordinary pig irons.

(10.) Phosphorus steel from common pig irons.

(11.) Chilling irons, malleable irons, strong machinery irons, semi-steel and steel castings from ordinary grades of mineral fuel pig irons.

The special features of Gordon's converter are the durability of the sides and bottom, and the tuyere, which dips into the bath through side-holes piercing the shell, and is moved into and out of the metal, automatically, by the action of the blast.

Referring to the accompanying illustrations: (*Plates IX to XII.*)

*A*, is a fire-clay tuyere.

*B*, is a gas pipe, turned on its upper end, the turned end fitting neatly into the holder *C*, but not secured thereto.

*C*, tapered tuyere holder, fitted into the piston *E*, secured by a double bayonet catch.

*D*, tapered wrought sleeve, threaded on to *C*, gripping the tapered end of *A*.

The holder *C*, sleeve *D* and pipe *B*, are to be in duplicate and adjusted to each-clay tuyere ready for insertion when the cylinder and tuyere are thrown into position, as shown in dotted lines.

*E*, small piston, preventing the free escape of the blast, forming hold fast for *C*.

*F*, openings for the passage of the blast into the tuyeres.

*G*, piston for raising or lowering the tuyeres.

*H*, valve, seating at *I*, the stem of which plays through the head of cylinder at *J*.

*K*, handle of cram screw, used to fix the valve stem at any point of its downward stroke.

*M*, conduit, leading from upper part of cylinder.

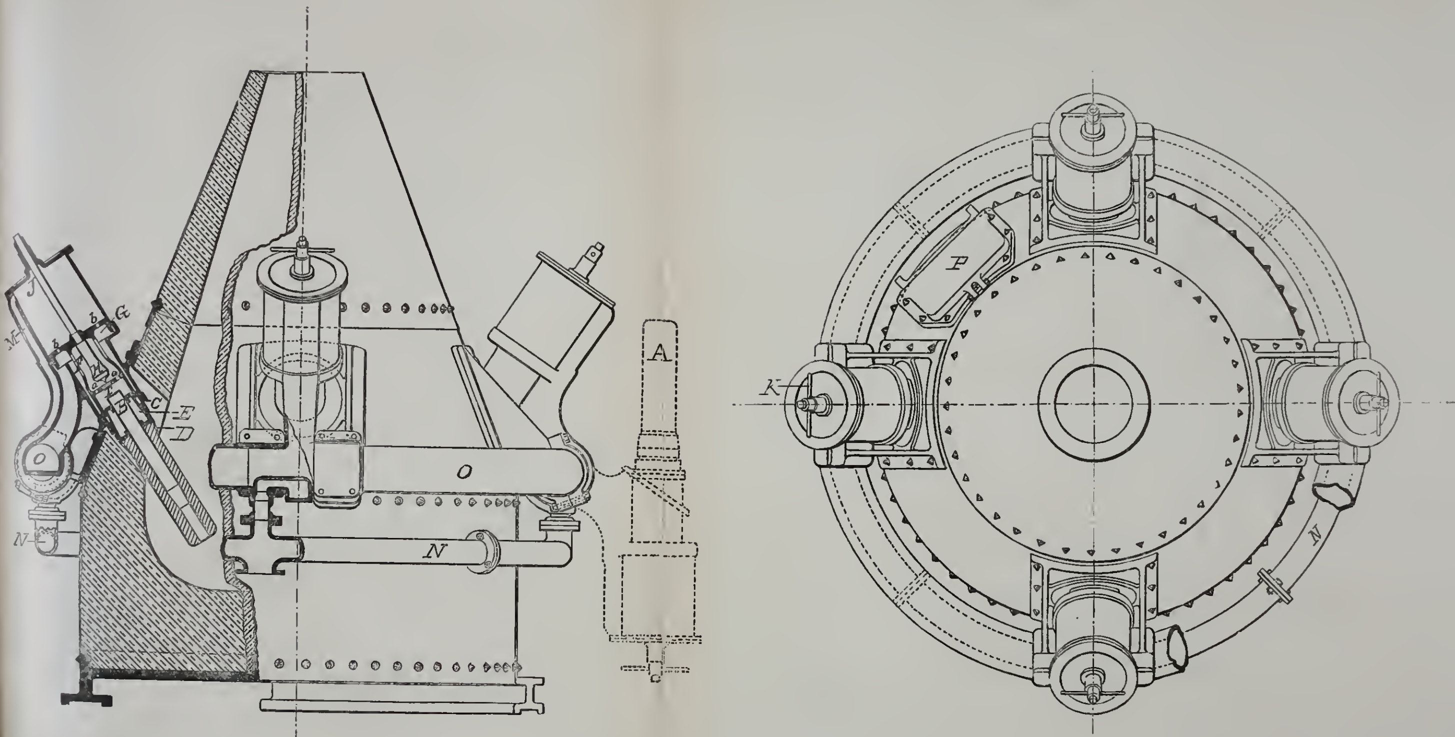
*N*, a discharge pipe, common to all the tuyeres, having a single exhaust valve.

*O*, main blast pipe.

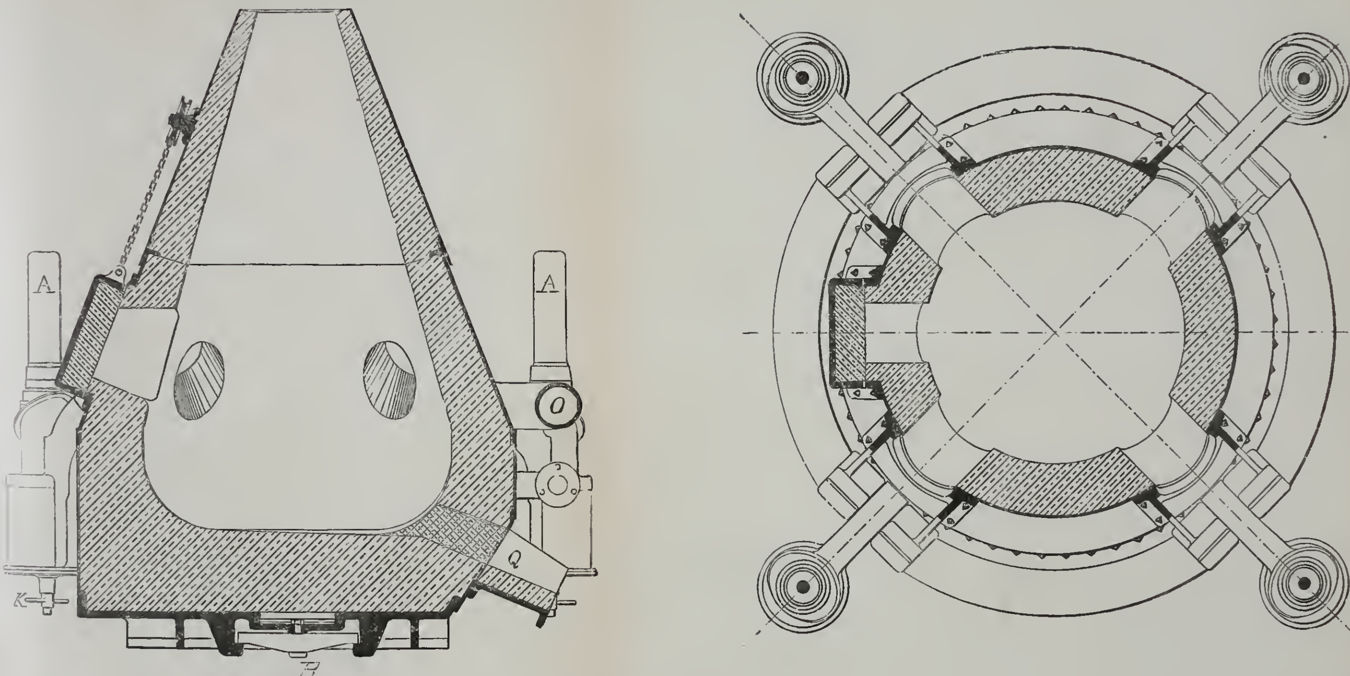
*P*, charging door.

*Q*, tapping hole.

*R*, cleaning door.




Details of the Gordon Converter.




Details of the Gordon Converter.

The operations are carried on as follows:

The exhaust valve to pipe *N* is left open at first and the blast admitted through the main *O*. There being no pressure in the cylinder on top of the piston, the latter remains up against the head. The valve *H* at this moment is seated, so that the blast, which enters through the slots *F*, is not wasted, the only escape being through the holes *a*, *a*. The metal is poured through the charging door *P*, the exhaust to pipe *N* is then closed, so that the blast passes through the holes *b*, *b*, drilled in the piston from which the tuyeres depend, and the latter assisted by gravity and pressure of blast upon the unbalanced piston *E*, descends into the metal. The valve *H*, stopped at the proper point by the nut *L*, unseats, and the total pressure reaches the bath through the tuyeres. The holes *a*, *a*, on each side of the valve seat *I*, admit air enough to keep the tuyeres clear of the metal, until the valve *H* is quite opened.

When the blow is over, the exhaust to pipe *N* is opened, so that the pressure of blast is exerted only on the under side of the piston, which causes it to ascend, and at the same time remove the tuyeres from the bath. As there is but one common exhaust worked from the pulpit, all the tuyeres are withdrawn simultaneously, the metal may then be tapped.

To replace the tuyeres, the piston is kept against the head of the cylinder, and the apparatus is tilted into the position, shown by the dotted lines.

The stem of the valve *H* is used to force the piston upwards, so that the tuyeres stand out and are easily got at.

The piston is prevented from revolving by stops on its under side (not shown in drawings) and, by seizing the sleeve *D* with a pair of tongs, the tuyere holder *C* may be disengaged, and a new set placed in. This operation is performed quickly and does not necessitate the stopping of the engine.

The piston *E* is scored all around, so that sufficient blast may pass out to keep the tuyere holes, in the side of the converter, free from slag.

From this description, it will be seen that the mechanism used in moving the tuyeres is entirely outside of the converter, and being preserved by the cool blast, is not liable to destruction by the heat.

It will also be seen that, although all the motions are automatic, the construction remains very simple and allows of an efficient control of all the parts at any time during the operations.

The fourth and last process, based on the Bessemer principle, which I shall describe briefly, is the Avesta process.

The Avesta process is really a scientifically constructed and conducted Bessemer process, on a small scale.

* The converter is suspended on trunnions like the ordinary Bessemer converter, but instead of the expensive hydraulic machinery used in turning, it is turned by one man by means of a crank.

The converter in use is only 1·4 metres high and one metre in diameter. The holes from the tuyeres cover an area equal to that of a circle 200 millimetres in diameter. There are ninety holes, about three to three and one-half millimetres in diameter, and the area is so calculated that after the blast has passed through the metal, there is little or no free oxygen left in the escaping gases.

The charge weighs from 170 to 765 kilograms, and only eight-tenths per cent. of seventy per cent. ferro-manganese is used to recarbonize.

The pressure of blast is 1·04 kilos to the square centimetre. The bottom is forced into place by a screw arrangement and can readily be detached and replaced.

I give below two analyses and physical tests of the metal produced by this process:

| *C.* | *Si.* | *Mn.* | *P.* | *S.* | *T.S.* | *E.* |
|---|---|---|---|---|---|---|
| 20 | ·05 | ·31 | ·051 | — | 35 K per square mm. | 25% in 200 mm. |
| 25 | ·11 | ·34 | ·05 | — | 37 | 30 |

Slag tests by Eggertz show from ·05 to ·5 per cent.

It is interesting and instructive to know that Mr. W. F. Durfee, of Bridgeport, Conn., anticipated the first three of the above processes by about twenty-two years, and actually built, in 1864, a converter exactly similar in principle, and differing but little in detail from those described.

If he had had the means or opportunity of continuing his

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* Oesterreichische Zeitschrift. 1884. By Professor Josef von Ehrenwerth. Translated by J. P. L. Westesson.

experiments, he would undoubtedly have produced a product equally good as that of the Clapp-Griffiths, or other similar processes. *Plate XIII* shows a sectional elevation of the Durfee stationary converter.

In concluding my remarks, I would state that I consider it absolutely certain, that one of the above methods will very shortly supersede puddling.

Enough money has been invested to render it certain, that all the difficulties which invariably arise in attempting something

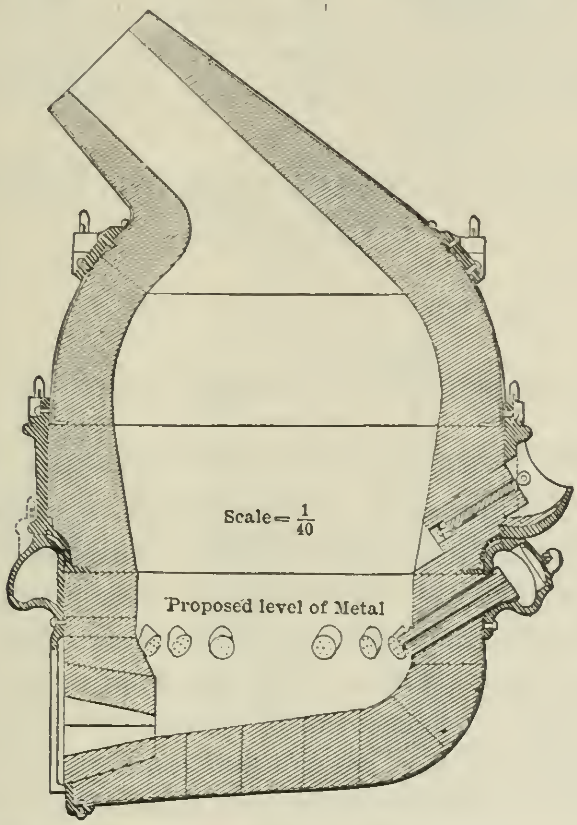


PLATE XIII.—The Durfee Stationary Converter.

new, will be solved. There can be no more steps backward and the puddling furnace is, therefore, inevitably doomed.

I believe, however, that in practice it will be found that there are two or three very important difficulties that will have to be overcome before steel entirely supersedes iron.

It is well known that a tolerably *good* bar iron can be made from high phosphorus pig, while the same pig converted into Bessemer steel is utterly worthless. The reason for this must be discovered and the cause removed.

Again, iron is fibrous (at least to some extent) even when made from the commonest stock, and although it will not show much elongation, will bend sooner than break, whereas steel made from the same stock is apt to be as brittle as glass, a sharp blow of a hammer often sufficing to crack the finished bar or plate. If some one will only discover how to make steel fibrous, the problem will be solved at once. Perhaps the Avesta process, by introducing a little slag into the steel, accomplishes this object.

There is no question, however, but that the material already made by these new processes will supplant iron for nine-tenths of the purposes for which iron is used, and we may expect in the next few years a marvellous growth in the number of these small converters.

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# GLIMPSES OF THE INTERNATIONAL ELECTRICAL EXHIBITION.

By Professor Edwin J. Houston.

(*Continued from Volume CXX, page 64.*)

## No. 8.—Reis's Invention of the Articulating Telephone.

The radical difference in principle that is claimed to exist between the transmitting instruments of Bell and those of Reis would naturally lead the unpredjudiced student to expect to find marked differences in their mechanical structure. Such differences, however, do not exist. On the contrary, limiting the inquiry to a comparison of Reis's various forms of transmitters with those in general commercial use to-day, we will find resemblances of the most marked character. Such resemblances establishing the fact we have already insisted on elsewhere, that Bell's contribution to the articulating telephone consisted in the production of a modification of an existing type of apparatus, and not the invention of a new genus.

Since the magneto-electric transmitter, such as described by Bell in his first patent, is in but comparatively limited use, we will exclude such apparatus from the present comparison.

Directing this comparison first to the mechanical structure, and second to the manner of operation of the various transmitters, it will be noticed that all transmitters of the type under consideration consist, so far as their mechanical structure is concerned, of three distinct parts, viz.:

(1.) The speaking tube, or mouth piece.

(2.) The diaphragm, or membrane.

(3.) The contact pieces, or apparatus for varying the contact.

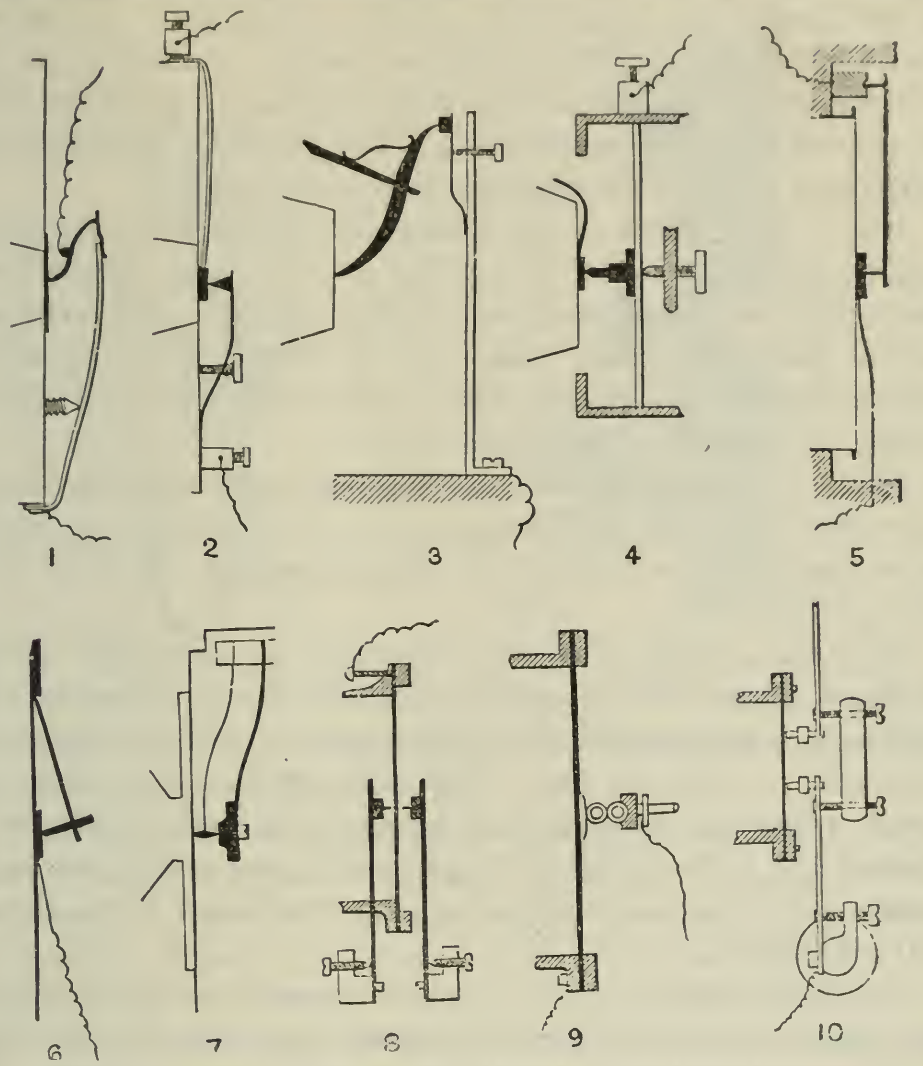


FIG. 10.—COMPARISON OF REIS AND MODERN TRANSMITTERS.

In *Fig. 10*, which in common with *Figs. 11, 12, 13 and 14* is taken from the work of Prof. S. P. Thompson on the "Telephone," only necessary parts are represented. The relative positions of the contacts and the diaphragm are, however, clearly shown in all.

In the upper row of sketches, from No. 1, to No. 5, inclusive, are shown various forms of transmitters, designed and constructed by Reis.

No. 1, is a sketch of Reis's original human-ear transmitter, shown in our previous article, in *Fig. 1*. The platinum tipped end of the bent lever and its loose contact with the platinum point of the

spring, together with their relations to the membranous diaphragm, are clearly shown.

No. 2, is a sketch showing the details of mechanical structure of the transmitting apparatus in Reis's bored-block transmitter, shown in our *Fig. 3*. The platinum contact is attached to the centre of the diaphragm, and has resting against it a platinum point on the end of an adjustable spring. The battery connections and relations of parts to the diaphragm are as indicated.

No. 3, is a sketch of the mechanical structure of the Reis-Legat transmitter, shown in our *Fig. 5*. The long, curved lever attached at one end to the centre of the diaphragm, and furnished with a platinum contact point that is pressed with a regulable pressure against a platinum point borne on the end of an elastic spring, is arranged in the manner shown.

No. 4, is a sketch of the Reis (Horkheimer) transmitter, shown more fully in our *Fig. 6*. The platinum contact points are placed respectively on the middle of the diaphragm, and at the end of the regulable screw.

No. 5, is a sketch of Reis's cabinet form of transmitter, which is shown more fully in our *Fig. 7*. In No. 5, however, the diaphragm is represented, for comparison, as vertical, instead of horizontal, as when in use. The heavy vertical line, with the contact point near its lower end, represents the right-angled piece of metal *h, g, i,* of our *Fig. 7*. Its platinum contact piece rests with variable contact against the platinum point attached to the centre of the diaphragm.

It will be observed that in all of these forms of early Reis transmitters, except the last, means are provided for regulating the degree of contact or pressure between the contact pieces. In the last form, as will be readily understood, no such regulating device is required, since such adjustment is secured by the weight and inertia of the movable or upper contact piece.

No. 6, is a sketch of Berliner's transmitter. As we have not yet described these forms of transmitters, we will give more detailed drawings of the same. In *Fig. 11*, is shown the essential parts of the Berliner transmitter.

The contact piece *E*, is securely attached to the centre of the diaphragm. A second contact piece, *k*, of the form shown, is hung from the arm *I*, which is loosely jointed at *N*, so as to per-

mit the contact *k*, to be pressed against *E*, by the weight of the swinging contact and its supporting arm. The electrical connections are as shown in the figure.

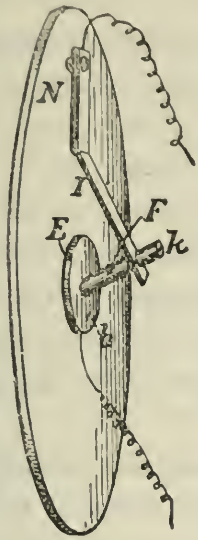


FIG. 11. THE BERLINER TRANSMITTER.

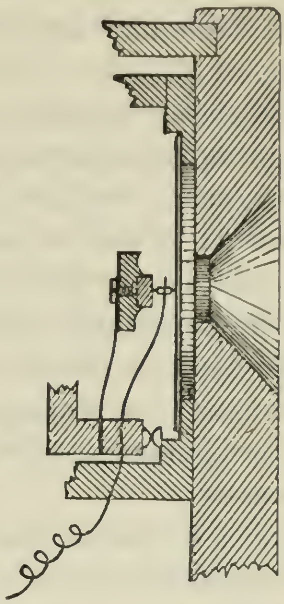

FIG. 12. THE BLAKE TRANSMITTER.

No. 7, is a sketch of the Blake transmitter. A more complete representation of the essential parts of this transmitter, omitting the induction coil, is shown in *Fig. 12.*

The Blake transmitter, as shown in the drawing, has its mouth piece formed by a conical hole bored in a block of wood, with the diaphragm in front of the smaller end of the hole, as in Reis's bored-block transmitter. Both contact points are mounted on springs. The first contact consists of a small metallic spike, or pin, of any non-corrodable metal. This contact is thus referred to in the specification of the British Patent, viz:

"It is desirable that it should be formed of, or plated with, some metal like platinum or nickel, which is not easily corroded. It may be attached directly to the diaphragm, but I prefer to support it independently, as shown, upon a light spring.

The other electrode is attached to a comparatively heavy weight, also supported by a spring, as shown. Of this electrode, the specification states: "This weight may be of metal, which may serve directly as the electrode, but I have obtained better results by applying to it, at the point of contact with the other electrode, a piece of gas-coke, or a hard-pressed block of carbon."

These contacts, with their supporting springs, and their posi-

tions with respect to the diaphragm and mouth piece, are show in sketch No. 7.

Nos. 8, 9, and 10, are various forms of transmitters devised by Edison, and described, or referred to by us in the article on "Edison's Telephonic Inventions." In No. 8, the diaphragm has a contact point on each of its sides; No. 9, shows rubber hose replacing the elastic metallic springs ordinarily employed; No. 10, is an interrupting transmitter, with duplicated contacts.

Comparing the mechanical structure of the above apparatus with one another, it will be observed that Reis's No. 1, or original apparatus, contains the three essential portions found in all the others, viz., the mouth piece, the diaphragm, and the contact points, placed in an electric circuit, and so arranged as to cause their degree of contact, and consequently their electrical resistance, to vary with the movements of the diaphragm under the influence of the sound-waves.

No. 2, closely resembles the Blake transmitter, in that one of the contacts is supported on an elastic spring. This is true of all of Reis's transmitters.

No. 4, still more closely resembles the Blake transmitter, as will be seen by the comparison of similar parts in each.

No. 5, resembles both the Beliner and the Blake transmitters, in the fact that the weight and inertia of the swinging contact are utilized for producing variations in the degree of contact on the movements of the diaphragm.

The resemblance of Nos. 8, 9, and 10, with the various forms of Reis transmitters, will be evident on comparing similar parts.

In all the later forms of transmitters shown, from No. 6, to No. 10, inclusive, the three essential parts of the instrument, viz., the mouth piece, the diaphragm, and the contact points are not only present, but also sustain identically the same relations to one another as they do in the original Reis apparatus. Indeed, as is evident, they are in most cases almost exact imitations of Reis's apparatus. As far as their mechanical structure then is concerned, a careful comparison fails to reveal any difference between the original apparatus which Reis constructed for the purpose of transmitting articulate speech, and the modified apparatus of later days. And yet it is claimed that the former apparatus are not true articulating telephones while the latter are.

Since the transmitting telephone operates mechanically on the

electrical circuit, and transmits articulate speech solely in virtue of such mechanical action, if no mechanical differences in the structure of Reis's forms of apparatus can be pointed out by the advocates of Bell, then we submit that they must in fairness recognize Reis as the true inventor of the articulating telephone, and Bell as the modifier only.

The description left by Reis of the construction of his various forms of transmitters is, beyond doubt, correct in all its details, and is such as would enable any skilled mechanic to go to work now and produce apparatus entirely similar to those described.

Let us now proceed to the second branch of the enquiry, viz., to the method of operation of the early Reis transmitters.

After having given a full and correct description of the mechanical structure of his apparatus, Reis proceeds to explain the method of its operation. Whether such explanation is correct or not, does not appear to us to alter the facts of mechanical structure of the apparatus. If the description left by Reis is such a full and exact one as will enable a skilled mechanic to reproduce the apparatus, and if such reproduced apparatus, without any modification or change whatever, is capable of transmitting intelligible, articulate speech, then Reis invented the articulating telephone, and publicly disclosed his invention in such a full, clear and exact manner as to enable others to make and use the same, and he therefore must be awarded priority of invention over Bell.

Of course, in the preceding it is understood that along with a full description of the mechanical structure of the apparatus, the inventor has added an explanation of the manner in which it was to be used. It was, of course, to be clearly stated that the transmitter was to transmit speech, and the receiver was to receive it. Such a description is not wanting. The person is to talk or sing against the transmitting membrane, or into the speaking tube, or its vicinity, and the listener is to place his ear near or close to the receiving diaphragm. Nothing else is necessary. Let, us therefore, look into this in connection with Reis's explanation of the manner of operation of the different parts.

That explanations as to the method of using the apparatus are not wanting, the following quotation will show, for example, in Reis's article, entitled "On Telephony by the Galvanic Current," published in the *Jahresbericht*, of the Physical Society of Frankfurt-am-Main for 1860–61, we find the following, viz.:

"If now tones, or combinations of tones, are produced in the neighborhood of the cube, so that waves of sufficient strength enter the opening *a*, they will set the membrane *b*, in vibration. At the first condensation, the hammer-shaped little wire *d*, will be pushed back. At the succeeding rarefaction, it cannot follow the return vibration of the membrane, and the current, going through the little strip (of platinum), remains interrupted so long as until the membrane, driven by a new condensation, presses the little strip (coming from *p*) against *d*, once more. In this way each sound-wave effects an opening and a closing of the current.

"But, at every closing of the circuit, the atoms of the iron needle, lying in the distant spiral, are pushed asunder from one another. (Müller–Pouillet, *Lehrbuch der Physik*, see page 304, of vol. ii., fifth edition.) At the interruption of the current, the atoms again attempt to regain their position of equilibrium. If this happens then in consequence of the action and reaction of elasticity and traction, they make a certain number of vibrations, and yield the longitudinal tone of the needle. It happens thus when the interruptions and restorations of the current are effected relatively slowly. But if these actions follow one another more rapidly than the oscillations due to the elasticity of the iron core, then the atoms cannot travel their entire paths. The paths travelled over become shorter the more rapidly the interruptions occur, and in proportion to their frequency. The iron needle emits no longer its longitudinal tone, but a tone whose pitch corresponds to the number of interruptions (in a given time). But this is saying nothing less than that the needle reproduces the tone, which was imparted to the interrupting apparatus."

Omitting the explanations as to the theory of its operations, the above clearly states the manner in which Reis intended his apparatus to be used. The receiving instrument being placed in the circuit of the transmitter and a voltaic battery, as elsewhere directed, one talks or sings into the mouth piece of the transmitting apparatus, while another listens at the receiving apparatus. All this precisely as in the case of the so-called modern invention.

So, too, in a letter written in English by Reis, in July, 1863, to Mr. Ladd, of London.

* * * * * * * * * *

"Tunes and sounds of any kind are only brought to our concep-

tion by the condensations and rarefactions of air or any other medium in which we may find ourselves. By every condensation, the tympanum of our ear is pressed inwards; by every rarefaction, it is pressed outward, and thus the tympanum performs oscillations like a pendulum. The smaller or greater number of the oscillations made in a second gives us, by help of the small bones in our ear and the auditory nerve, the idea of a higher or lower tone."

* * * * * * * * * *

"The apparatus consists of two separated parts: one for the singing station *A*, and the other for the hearing station *B*." See *Fig. 12*.

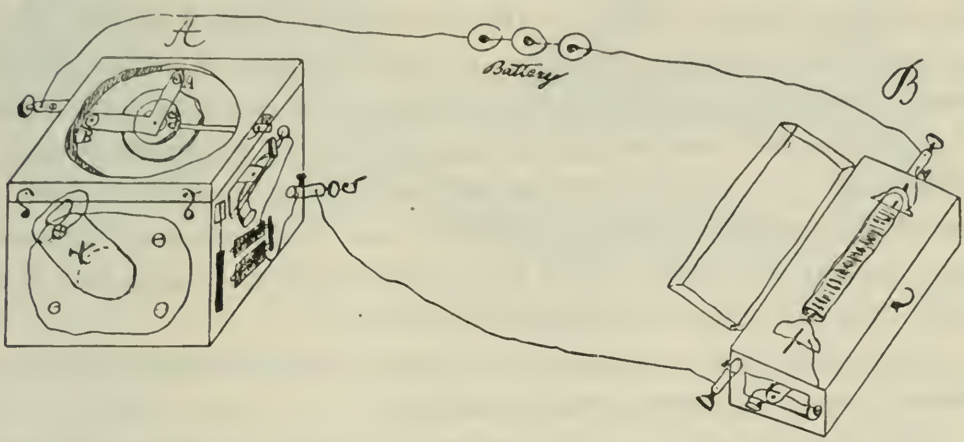


FIG. 13.—PEN AND INK SKETCH OF TELEPHONE ACCOMPANYING REIS'S LETTER TO LADD.

"The apparatus *A*, a square box of wood, the cover of which shows the membrane *c*, on the outside, under glass. In the middle of the latter is fixed a small platina plate, to which a flattened copper wire is soldered on purpose to conduct the galvanic current. Within the circle you will further remark two screws. One of them is terminated by a little pit in which you put a little drop of quicksilver; the other is pointed. The angle, which you find lying on the membrane, is to be placed according to the letters with the little whole (hole) *a*, on the point *a*, the little platina foot *b*, into the quicksilver screw, the other platina foot will then come on the platina plate in the middle of the membrane.

"The galvanic current coming from the battery (which I compose generally of three or four good elements) is introduced at the conducting screw near *b*, wherefrom it proceeds to the quicksilver, the movable angle, the platina plate and the complementary telegraph to the conducting screw *s*. From here, it goes through the conductor to the other station *B*, and from there it returns to the battery.

"The apparatus *B*, a sonorous box, on the cover of which is placed the wire-spiral with the steel axis, which will be magnetic when the current goes through the spiral. A second little box is fixed on the first one, and laid down on the steel axis to increase the intensity of the reproduced sounds. On the small side of the lower box, you will find the correspondent part of the complementary telegraph. [The device here alluded to was a small electro-magnetic signaling device, corresponding to the call-bell.]

"If a person sing at the station *A*, in the tube *x*, the vibrations of air will pass into the box and move the membrane above; thereby the platina foot *c*, of the movable angle will be lifted up and will thus open the stream at every condensation of air in the box. The stream will be re-established at every rarefaction. For this manner the steel axis at station *B*, will be magnetic once for every full vibration, and as magnetism never enters nor leaves a metal without disturbing the equilibrium of the atoms, the steel axis at station *B*, must repeat the vibrations at station *A*, and thus reproduce the sounds which caused them.

"*Any* (the italics are Reis's) sound will be reproduced, if strong enough to set the membrane in motion."

Here the description of the mechanical structure of the apparatus, the disposition of its various parts, and the manner in which they are intended to be used, are far more explicit than in many patent specifications, and in particular more explicit than the directions to be found in the specification of Bell's so-called telephone patent of 1876.

Besides the above, we quote Prof. Thompson's translation of a prospectus that was issued with the Reis apparatus, sold by Albert of Frankfort.

TELEPHON.

"Each apparatus consists, as is seen from the above illustration, of two parts: the telephone proper, *A*, (*Fig. 14*) and the reproduction apparatus (Receiver) *C*. These two parts are placed at such a distance from each other, that singing, or the tones of a musical instrument, can be heard from one station to the other in no way except through the apparatus itself.

"Both parts are connected with each other, and with the battery *B*, like ordinary telegraphs. The battery must be capable of effecting the attraction of the armature of the electro-magnet

placed at the side of station *A*, (3—4 six-inch Bunsen's elements suffice for several hundred feet distance).

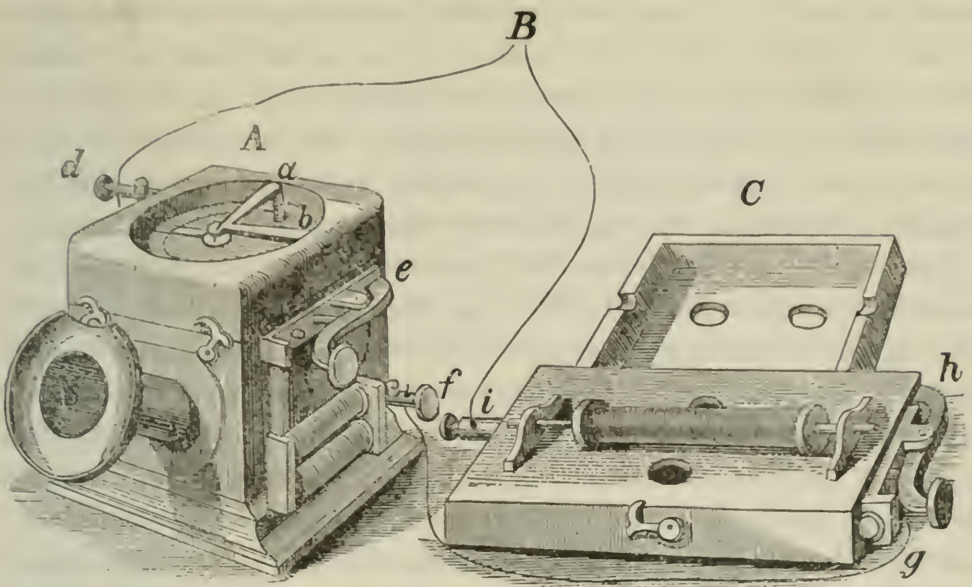


FIG. 14.—ILLUSTRATIONS OF APPARATUS AND CIRCUIT CONNECTIONS ACCOMPANYING REIS'S PROSPECTUS.

"The galvanic current goes then from *B*, to the screw *d*, thence through the copper strip to the little platinum plate at the middle of the membrane, then through the foot *c*, of the angular piece to the screw *b*, in whose little concavity a drop of quicksilver is put. From here, the current then goes through the little telegraph apparatus *e*, *f*, then to the key of station *C*, and through the spiral past *i*, back to *B*.

"If now sufficiently strong tones are produced before the sound-aperture *S*, the membrane and the angle-shaped little hammer lying upon it are set in motion by the vibrations; the circuit will be once opened and again closed for each full vibration, and thereby there will be produced in the iron wire of the spiral at station *C*, the same number of vibrations which there are perceived as a tone or combination of tones (chord). By imposing the little upper case firmly upon the axis of the spiral, the tones at *C*, are greatly strengthened.

"Besides the human voice (according to my experience) there also can be reproduced the tones of good organ pipes from *F*—*c*, and those of a piano."

A careful consideration of the preceding quotations will render it clear that no objections can be found with the descriptions that

Reis gives of the mechanical structure of his apparatus, nor of the manner in which it is to be used in the transmission and reproduction of *all kinds of sounds*, including, as is repeatedly claimed by Reis, articulate speech. Nor, indeed, are we aware that any such objections have been urged, unless it be the very remarkable one that Reis never intended his apparatus for the transmission of speech, but only for the transmission of musical sounds—a statement of marvellous assurance, in view of the very explicit statement of Reis that his apparatus was designed to transmit speech, and that such speech was actually transmitted. The argument made by the advocates of Bell against the claims made for Reis as to the invention of the telephone, refers almost entirely to the theory of its actions as advanced by Reis in the preceding quotations. It is insisted that the makes and breaks referred to by Reis were absolute and complete, and were followed by absolute and complete cessations of the electrical current in the circuit of the transmitting and receiving instruments. That such currents cannot by any possibility act to reproduce articulate speech, and since, as they claim, Reis intended to describe such makes and breaks, his apparatus never could have transmitted or reproduced such speech.

It never seems to have occurred to such objectors that if even the smallest possibility of misunderstanding existed as to Reis's interpretation of the words "make" and "break," a spirit of but ordinary fairness would have led to the inquiry as to whether the original Reis apparatus would transmit articulate speech as he and others claimed, in which case it would appear that either,

(1) The assumption made by them that makes and breaks, complete and absolute, cannot transmit articulate speech is untrue; or,

(2) That Reis did not intend to convey the same meaning by his use of the words makes and breaks, as they assumed him to do, but that the makes and breaks were the variations in the electrical resistance of the circuit, that exactly corresponded to the variations in the movements of the transmitting diaphragm when acted on by the impinging sound-waves, or, as Reiss says in the *Jahresbericht* article, "to set up vibrations whose curves are like those of any given tone or combination of tones;" or,

(3) That, although the description given by Reiss of the manner in which his apparatus actually operated, was inaccurate, yet

the mechanical structure of the apparatus, the relative proportions of its parts, and the method in accordance with which they were intended to be used, were such as would enable them to do all that their inventor claimed.

That very grave doubts fairly exist as to the meaning Reis intended to be given to his use of the words "make" and "break," there can be no question. The mechanical structure of the apparatus itself, and the masterly manner in which Reis, in the *Jahresbericht* article, considers the nature of the curves in the case of compound sounds, prove beyond reasonable doubt that he clearly understood the principles according to which the telephone transmitter varied the intensity of an electrical current, so as to permit it to reproduce in the receiver the sounds made at the transmitter.

This matter will, perhaps, be made clearer by an examination of the Reis and other transmitters, shown in *Fig. 10*, while discussing the method in which they act while in actual operation.

Assuming, for the sake of argument, the correctness of the explanations generally given as to the manner of operation of, say, any of Edison's contact transmitters, the explanation would be as follows, viz.: The sound-waves impinging on the diaphragm impart to it vibrations similar, in their movements and complexity, to the vibrations they would also produce in the ear of a person standing near the speaker. The movements so produced in the diaphragm vary the pressure of the contact points and cause corresponding variations in the electrical resistance of the circuit in which the variable-resistance contact points are placed. These variations acting on the magnetic receiver at the receiving end of the circuit, reproduce in its diaphragm the motions of the transmitting diaphragm, so that one listening at the receiving instrument, hears whatever sounds are made at the transmitting instrument.

In order to avoid the too great movements of the contact points, by means of which one of them would be thrown completely off from the other, *and thus be prevented from receiving the impress of the movements of the diaphragm while it was separated from it*, one or both of the contact points are mounted on springs, the pressure of which against the other point on the diaphragm is controlled by regulable screws. When properly adjusted, the

contact point follows the motions of the diaphragm, and instead of actually leaving it completely and entirely, only leaves it at certain points of its surface, thus varying the cross section of the conducting surfaces in contact, and, of necessity, their electrical resistance.

If it were a matter of indifference whether the contact point occasionally left the diaphragm long enough to prevent it from receiving the impress of all its to-and-fro movements, the regulating screw would be unnecessary. The presence of this screw when taken in connection with the elastic support of one of the contacts, would appear clearly to show that the inventor intended, when he produced such a mechanical structure, to avoid the too free movement of the contact. That he intended the contact to be influenced by all the movements of the diaphragm; that he desired especially to avoid such a free movement of the contact point as would prevent it from leaving the diaphragm for such a length of time as to cause it to miss some of the to-and-fro movements of the diaphragm.

In the Berliner transmitter, the weight and inertia of the swinging contact permits the suppression of the elastically-mounted contact and its adjusting screw. In the Blake transmitter the elastic support is given to both contacts, their weight and inertia permitting the suppression of the adjusting screw.

Applying the preceding description of the mode of operation of Edison's, Berliner's and Blake's transmitters to sketches 1, 2, 3, 4, and 5, of Reis's transmitters, we fail, after careful thought to perceive any differences in their mode of operation. Their mechanical structure and the relative arrangement and proportion of their parts are practically the same. The action of the sound-waves on the diaphragm and its action on the contact points are the same, so that, whatever one does, the other does; whatever one is, the other is.

Now, in considering the only fair and proper meaning to attach to Reis's use of the words "make" and "break," we would call attention to the following important points; viz., that where necessary to prevent such makes and breaks as would be injurious to proper action, we find in all of Reis's transmitters:

(1.) Elastically-supported contact points.

(2.) Regulable screws provided for varying as desired the pressure of the contact point against the diaphragm, and that,

moreover, when such devices are unnecessary, as in No. 5, they are markedly absent.

In view, then, of these facts, clearly shown by the mechanical structure of his apparatus, we find it difficult to understand how any one is willing to maintain that Reis intended that the "makes" and "breaks" he alludes to in his description of the theory of operation of his apparatus, were of such a nature as to produce such a free movement of the variable contact point, *as would throw it completely off or away from the diaphragm, so as to cause it to lose some of its to and fro movements.* That such was never intended, is not only proved by the elastically supported contact and its regulating screw, but also by the direct statements of the inventor. He speaks thus of the contact, "the little hammer-shaped wire *d*, being pushed back," at each condensation, which would be clearly impossible, if it lost some of the condensations. He asserts that "the movable angle (of his cabinet apparatus) will be lifted up and will thus open the stream at every condensation of air in the box, the stream will be re-established at every rarefaction."

That Reis could not have intended his use of the words "make" and "break" to signify such a separation of the elastically-supported contact as would remove it from the diaphragm long enough to permit it to miss some of its vibrations, should need no further proof than a careful study of the very able manner in which he discourses, in his *Jahresbericht* article, the graphic representation of the alternate condensation and rarefaction of the air in sound-waves. His insight into this matter was remarkably clear, considering the time at which he wrote, and even the most advanced science of the present day has but little to add to what he has stated as to the representation, by means of graphic curves, of the variations in the density of the air produced by means of sound-waves. His writings show, in the clearest manner, that the prime condition he constantly kept before him, in order to solve the electrical transmission of sounds of all kinds, was the necessity of obtaining an exact reproduction, in the diaphragm of the receiving instrument, of the movements of the diaphragm of the transmitting instrument under the influence of the sound-waves. "The function of the organs of hearing, therefore, is to impart faithfully to the auditory nerve every condensation and rarefaction occurring in the surrounding medium." "That which is perceived by the auditory

nerve is, therefore, merely the action of a force affecting our consciousness, and as such may be represented graphically, according to its duration and magnitude, by a curve." "Our ear can perceive absolutely nothing more than is capable of being represented by similar curves, and this method is completely sufficient to bring before our clear consciousness every tone and every combination of tones." "As soon, therefore, as it shall be possible, at any place and in any prescribed manner, to set up vibrations whose curves are like those of any given tone *or combination of tones* (the italics are my own), we shall receive the same impression as that tone or combination of tones would have produced upon us."

"Taking my stand on the preceding principles, I have succeeded in constructing an apparatus by means of which I am in a position to reproduce the tones of divers instruments, yes, and even, to a certain degree, the human voice."

Can any reasonable doubt remain, after reading the above, that Reis could have intentionally designed his apparatus to produce effects contrary to what he so clearly stated as necessary for its success? This will, perhaps, be made still clearer from an inspection of the tables of curves accompanying his *Jahresbericht* article. These we will reproduce, as well as a translation of that part of the article alluding to them, even though we have quoted some of it previously. We will use for this purpose the translation introduced into the record of the "American Bell Telephone Company *vs.* Amos E. Dolbear, *et al.*"

"What our auditory nerve perceives is, then, simply the effect of a force coming within the range of consciousness, and this force can be represented, both as to duration and magnitude, graphically by a curve."

"Let $a, b$, (*Fig. 15*) represent any given time, and the curve above


FIG. 15.—GRAPHIC REPRESENTATION OF CONDENSATION AND RAREFACTION.

the line condensation (+), the curve below the line rarefaction (—), then any ordinate raised from the end of any abscissa will represent the degree of condensation, at the time represented by its base, in consequence of which the drum of the ear vibrates.

"Our ear can, under no circumstances, appreciate more than can be represented by these curves, and this, indeed, is entirely sufficient to give us a clear perception of any tone (*Ton*) or any combination of tones.

"If several tones (*Tonen*) are produced at the same time, the conducting medium is subjected to the influence of several simultaneous forces, and the two following laws will hold good. If the forces act in the same direction, the amplitude is proportional to the sum of the forces; if the forces act in opposite directions, the amplitudes are proportional to the difference of the opposing forces.

"If, for example, in the case of three tones, we draw the curve of condensation of each separately, then by a summation of the ordinates of corresponding abscissas, we can determine new ordinates and develop a new curve, which might be called the combination curve. This represents exactly what our ear perceives of the three simultaneous tones. The fact that the musician can distinguish the three tones need not surprise us any more than the fact that any one acquainted with the theory of colors can in green discover blue and yellow; but the combination curves in Plate I, (our *Plate III*,) show that this difficulty is a slight one, for in these curves all the relations of the components successively recur. In the case of chords, of more than three notes, the relations are not so readily seen from the drawing, Plate II, (*Plate IV*), for example. In the case of chords, however, the skilled musician also finds difficulty in recognizing separate notes.

"Plate III, (*Plate V*) illustrates discord (*Dissonanz*). Why discords impress us unpleasantly, I will leave my readers to judge at this time, though I may, perhaps, return to the subject subsequently in another paper.

"From the preceding, it follows:

"*First.*—Every tone and every combination of tones, on striking our ear, causes vibrations of the drum of the ear, the succession of which may be represented by a curve.

"*Second.*—The succession of these vibrations alone gives us a conception (*Sensation*) of the tone, and every alteration changes the conception (*Sensation*)."

The terms condensation and rarefaction as applied to sound-waves are entirely relative in their nature. A medium transmitting

a sound-wave is rarefied when its density is decreased, and condensed when its density is increased beyond what it originally was, the extent or ratio of the condensations or rarefactions, representing the amplitude of the sound-waves. Practically, then, the amplitude represents the amount of energy charged on the medium in order to mould it into waves. In the case of interfering waves, the amount and distribution of the energy in the resulting wave depends on the amount and distribution in the component waves. When the direction in which the energy acts is the same in, say, two waves, the amplitude of the resultant wave is the sum of the amplitudes of the two; if the direction is opposite, the amplitude of the resultant wave is the difference of the two. Two waves may completely obliterate each other, provided they simultaneously affect the same particles of the medium in opposite directions, with equal intensities, and for equal lengths of time; or, as it may be otherwise expressed, if the waves meet in opposite phases, are of equal amplitudes, and are of the same wave lengths.

Considering now the curve shown in the upper part of *Plate IV*, as resulting from the simultaneous action of the notes $c$, $e'$, $g$, and $c'$, it will be noticed that the condensation rises while the four notes are simultaneously condensing the air, but begins to fall when part of them are endeavoring to rarefy it, as is indicated, for example, between the third and the sixth abscissa, where a gradual fall is shown, while between the sixth and seventh abscissa, and for some distance beyond, the fall is more sudden. Now, although in a general sense, it is correct to regard the curve between the first and the 7½th abscissa as indicating a condensation of the medium propagating the wave, yet it is equally correct to regard all that part of the curve between the third and the 7½th abscissa as representing a rarefaction of the medium, superposed on the condensation, since a decrease of the condensation at any time is practically a rarefaction. Moreover, its effect is practically the same as that of a rarefaction since if the condensation moves the medium in one direction, the rarefaction moves it in the opposite direction.

Studying Reis's curves in this light, is it not clear that he never could have intended to use the words "make" and "break" in the sense ascribed to him, but that when he spoke of the interruption occurring at every condensation and rarefaction, he uses these terms in the sense above indicated. Does not the elastically-sup-

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Here

ported contact, with its adjusting screw, show that he did not intend the contact to leave the diaphragm completely, but that he wished it to follow its finer motions? Does he not say in the *Jahresbericht* article, "but the quality of the note depends upon the number of variations of amplitude (*Anschwellungen*) occurring in the same time." "Now my apparatus gives the number of the vibrations, but with far less strength than the original ones: though also, as I have cause to think, always proportional to one another up to a certain degree. But because the vibrations are throughout smaller, the difference between large and small vibrations is much more difficult to recognize than in the original waves, and the wave is therefore more or less indefinite."

If his apparatus, as he left it, with the elastically-supported contact, and its adjustable spring, will speak in 1885, with absolutely nothing added to it, is it in the light of 1876, that it has been made to work? Is it not rather in the very clear light of 1860, and 1861, when the *Jahresbericht* article was published?

There are two other points in the *Jahresbericht* article which throw some light on the meaning, which should be given to Reis's use of the words "make" and "break." The first of these is to be found in his description of the action of the core of the magnetizing spiral. "The intensity also of this tone is proportional to that of the original one; for, in proportion as this is more intense, the motions of the membrane are greater, the motions of the hammer, also, and finally the time during which the circuit remains opened is greater, and, consequently, up to a certain limit the motions of the atoms in the reproducing wire are greater, we perceiving them as greater vibrations in just the same way as we would have perceived the original sound-wave." If the "opening" of the circuit here referred to means, as we have suggested, its gradual increase in resistance, while the diaphragm was under the influence of the rarefaction, or while it was moving in a certain direction, then we can understand how the instrument could reproduce variations in the intensity of the transmitted sounds; but, if it mean a complete break, then, since it is difficult to understand how the circuit, if completely broken, can be anything more than broken, it is equally difficult to see how the duration of the complete break could effect the intensity.

Again, Reis's claims as to the capabilities of his instruments

"now in reference to the capabilities of the telephone," * * * "experiments showed that the sounding wire was capable of reproducing complete chords of three tones of the piano;" that is to say, it was capable of transmitting quality which would be clearly impossible, if the instrument acted on the "make" and "break" principle in the sense claimed by the advocates of Bell.

If the paragraphs in Reis's article, in which he refers to the "making" and "breaking" of the circuit stood by themselves, then it might be admissible to put the construction on them before referred to, but taken in connection with the other declarations and explanations of Reis, we do not see that such interpretation stands at all.

If, however, such interpretation be sustained, then it simply amounts to this: viz., that Reis did not understand the theoretical operation of his instrument. But we fail to see how this can injure his position as an inventor. If he produced an instrument whose mechanical structure was such as would permit it to reproduce articulate speech, and properly instructed others how to make and use it, then he is the true inventor of the same, no matter how erroneous his ideas may have been as to its theoretical operation. If, as is undoubtedly the case, scientific opinion of the present day is still uncertain as to what is the exact theory of the action of the articulating telephone, then Reis may justly be excused if he erred in his description of the same. Should Bell's theory of the undulatory character of the transmitted current, in the sense in which he claims it, be fallacious, as is by no means improbable, then are his claims to the modified forms of apparatus that he has produced to be regarded as untenable?

In the Legat description of Reis's apparatus, already referred to, we note the following in speaking of the movable contact: "It is advisable to make the arm *c*, *e*, longer than the arm *e*, *d*, in order that the least motion at *c*, may operate with the greatest effect. It is also desirable that the lever itself may be made as light as possible, *that it may follow the movements of the diaphragm* (our italics). Any inaccuracy in the operation of the lever *c*, *d*, in this respect will produce false tones at the receiving station." The necessity for the contact to follow the motions of the diaphragm is precisely what we have insisted on. Legat, for some reason or other, does not appear to have obtained any valuable results with the instruments with which he experimented.

It would appear to be an assumption, bordering on impertinence, to deny to the man whose genius created the most marvellous instrument of modern science, a knowledge of the simplest principles underlying the operation of the instrument he has constructed. It is incredible that he, who modelled his transmitting instrument after the human ear, who explained so thoroughly by curves the peculiarities of the motion of its tympanum, and who wrote, "the function of the organs of hearing, therefore, is to impart faithfully to the auditory nerve every condensation and rarefaction occuring in the surrounding medium; the function of the auditory nerve is to bring to our consciousness the vibrations of matter resulting at the given time, both according to their number and magnitude," could have so blundered, as to desire to obtain results that he especially designed the mechanical structure of his apparatus to avoid.

Any form of variable-contact transmitter will cease to properly operate if spoken to in too loud a tone, since in such a case the movable contact will be separated from the diaphragm too long to permit it to be impressed by all its motions. By the use, however, of the regulating screw the pressure of the elastically-supported contact may be varied, so as to permit a fair use with a loud tone. This is true with the Reis transmitters, and equally true of the others.

We again assert, therefore, that the Reis transmitters operate, when transmitting articulate speech, in precisely the same way as the modern receivers, and presumably in the very way that Reis intended that they should operate, but that, however, this may be, even admitting that he so strangely erred in his explanation of the way in which he conceived it to operate, then, nevertheless, *if his description of the mechanical structure of his apparatus, and of the manner in which it was intended to be used, is such as to enable a skilled mechanic with no other knowledge of the art than that imparted to him by Reis's publications and drawings, to make and use the same, then Reis is the first, true and only inventor, and to him must be awarded priority of invention over all others.*

Since the object of the contact pieces is to vary the electrical resistance of the circuit in which they are placed, by altering the extent of surfaces in contact, they must, of course, have been formed of some electrical conducting substance. Since, if such substance were liable to oxidation, it might, apart from the motions of the

diaphragm, thus introduce a varying resistance into the circuit, the substance must not be readily oxidized. Reis employed for his contact pieces metallic platinum. Berliner, Blake, and, indeed, nearly all later inventors have replaced the platinum by hard carbon, since Hughes pointed out its superiority. This material, though perhaps better in degree, does not differ in the manner of its operation, as is indeed shown by the fact that the Berliner or the Blake transmitters will operate satisfactorily when their carbon contacts are replaced by metallic platinum, or that conversely the Reis transmitter will operate if furnished with carbon contacts.

In the early history of the Reis-Bell controversy, it was denied by the advocates of Bell that it was possible to make the Reis apparatus talk. When, however, it was proved by the most unquestioned testimony, and by actual demonstrations, that the Reis apparatus could and would talk, instead of fairly according to him the merit of the discovery, they adopted the specious plea that even if the apparatus would talk, it was only in the light of the experience of Bell that it could be made to do so; that is, that the success of actual use of the Reis apparatus was by the use of the knowledge gained since 1876. Such reasoning would appear too illogical to need refutation. Let us, however, present the same reasoning in another light.

An apparatus designed by Reis to transmit articulate speech, made, we will say, in 1861, is left unnoticed in that strange way in which the world has too often failed to accept the gifts of genius, if born out of time. It slumbers amid the dust of age and neglect, while its inventor, unable to convince the world of its great value, at last dies disappointed and heart-broken. Temporarily forgotten, it is re-invented by another and accepted by the world as the greatest discovery of modern time, and no honors are deemed too great for its supposed inventor. Again brought to light, the original apparatus is compared with the later alleged invention and found to resemble it in a remarkable manner. Doing absolutely nothing but to remove the accumulated dust of many years, it is placed in circuit with another receiver, or, indeed, even with its own receiver, and lo! it talks. Surprised at this success, the experimenter searches for Reis's description of such apparatus and finds that he and others claim to have talked through such apparatus long ago. What then should be his indignant surprise, as one

possessing that true scientific instinct of desiring to know the truth for the truth's sake, to be told that Reis must have falsified his record when he stated that such an apparatus would talk; that had it not been for Bell, the Reis apparatus would never have spoken. If it be a telephone in 1885, why was it not equally a telephone in 1861, especially when it was designed to talk, and when, if the most solemn statements are to be believed, it did talk? It is not, perhaps, saying too much to add that a defence of such a character is open to grave suspicions of insincerity.

And yet, what is the position in which the advocates of Bell insist on placing him, in order to enable them to continue to maintain his patent rights in the United States? Do they not assume for him a declaration that might not unfairly be worded as follows: "I have made a grand and great discovery of so novel a character that I demand, for its protection, the broadest and most general patent that can be issued. I have discovered that if I use the regulating screw placed by Reis in an apparatus improperly called by him a telephone, and obtain a certain pressure of an elastically-supported contact against a diaphragm, that the apparatus will do what Reis and others claim that it did many years ago, but which I do not believe they ever accomplished. My discovery, therefore, is of so novel a character that I claim in general the use of electricity in the transmission of articulate speech, and consider it a sufficient proof of the infringement of my patent rights if any one hereafter succeeds in actually transmitting speech electrically."

Is Mr. Bell willing to permit others to continue to make such claims for him? We can hardly believe that his known sense of fairness will permit him to continue to do so. The credit that is legitimately due him, and which all are willing to acknowledge, should suffice, without his permitting others to endeavor to appropriate for him that due to Reis.

It has been said, "a century of Reis would not produce a speaking telephone," because Reis did not give the correct explanation of the manner of operation of his instrument. We beg leave to differ entirely from this statement. The apparatus of Reis, so far as its mechanical structure and the way in which it was designed to be used are concerned, are entirely independent of any theoretical explanations of how such apparatus operated to produce the

results for which they were designed. According to such reasoning, a century of Franklin would never produce a lightning rod, since Franklin, although he gave a full and correct description of the construction of his lightning rod, and explained how it was to be placed on the building it was designed to protect, alleged that the manner in which it operated was by drawing a hypothetical electrical fluid from the surcharged cloud and quietly conveying it to the ground. At the present, we do not believe in the fluid theory of electricity; therefore, there never was a lightning rod, and no such instrument can act as a lightning rod until we know the exact manner in which it lowers the higher potential of the cloud to that of the earth. Is not such reasoning nonsensical, and could it not be enlarged indefinitely?

It is an interesting fact that Bell approached the invention of his form of articulating telephone from very nearly the same standpoint as Reis; that is, from a study of the curves resulting from the combination of different tones, with, however, this difference. Reis designed his curves to represent the variations in the amplitude of the sound-waves, or the variations in the movements of the diaphragm of the receiving instrument. Bell, on the contrary, employed his curves to represent electrical undulations. Quoting from the specification of his U. S. Patent, No. 174,465, of March 7, 1876:

"Electrical undulations, induced by the vibration of a body capable of inductive action, can be represented graphically, without error, by the same sinusoidal curve which expresses the vibration of the inducing body itself, and the effect of its vibration upon the air; for, as above stated, the rate of oscillation in the electrical current corresponds to the rate of vibration of the inducing body; that is, to the pitch of the sound produced. The intensity of the current varies with the amplitude of the vibration; that is, with the loudness of the sound; and the polarity of the current corresponds to the direction of the vibrating body; that is, to the condensations and rarefactions of air produced by the vibration. Hence, the sinusoidal curve *A*, or *B*, *Fig. 4* (our *Fig. 16*), represents, graphically, the electrical undulation, induced in a circuit by the vibration of a body, capable of inductive action."

The horizontal line *a*, *d*, *e*, *f*., etc., represents the zero of current. The elevation, *b*, *b*, *b*, etc., indicates impulses of positive

electricity. The depression, *c, c, c,* etc., show impulses of negative electricity. The vertical distance, *b d,* or *c f,* of any portion of the curve from the zero line expresses the intensity of the positive or negative impulse at the part observed, and the horizontal distance

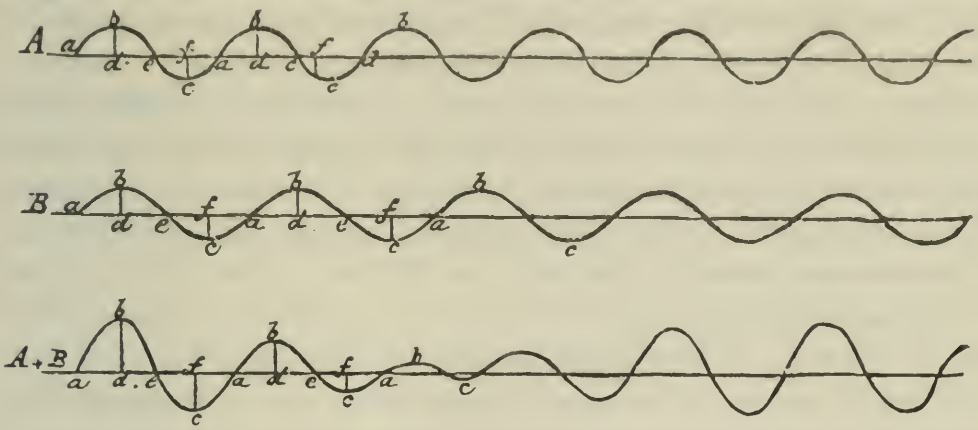


FIG. 16.—CURVES REPRESENTING ELECTRICAL UNDULATIONS FROM FIG. 4, OF BELL'S U. S. PATENT, NO. 174,465.

*a, a,* indicates the duration of the electrical oscillation. The vibrations represented by the sinusoidal curves, *B,* and *A, Fig. 4,* are in the ratio aforesaid, of 4 to 5; that is, four oscillations of *B,* are made in the same time as five oscillations of *A.*

"The combined effect of *A,* and *B,* when inducted simultaneously on the same circuit, is expressed by the curves *A + B, Fig. 4,* which is the algebraical sum of the sinusoidal curves of *A,* and *B.* This curve, *A + B,* also indicates the actual motion of the air when the musical notes considered are sounded simultaneously. Thus, where electrical undulations of different rates are simultaneously induced in the same circuit, an effect is produced analogous to that occasioned in the air by the vibration of the inducing bodies."

The difference between Reis and Bell, then, is as follows: Reis insisted on the necessity of reproducing in the diaphragm of the receiving instrument similar movements to those in the ransmitting diaphragm, and endeavored to obtain this result by an elastically-supported regulable spring, through the action of what he called makes and breaks. Bell also insisted on the reproduction in the receiving diaphragm of the motion of the transmitting diaphragm, but declared that in order to achieve this result exactly similar undulations must be given to the electrical current that traverses the wire between the two stations. Reis, it will be

observed, designed his curves to represent electrically the magnetization of the receiving electro-magnet, which, as Legat describes, "will be magnetized, and demagnetized correspondingly with the condensation and rarefaction of the mass of air," "and the armature belonging to the magnet will be set into vibrations similar to those of the membrane in the transmitting apparatus." Both inventors insisted on the necessity for an undulatory effect. Bell places it in the current as it leaves the transmitter; Reis in the magnetic field of the receiving magnet. Let us see, therefore, which explanation is the more nearly in accord with the facts as they are now generally accepted.

CENTRAL HIGH SCHOOL.

PHILADELPHIA, October 10, 1885.

(*To be continued.*)

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# INFLUENCE OF ELECTRIC STORMS ON SUBTERRANEAN TELEGRAPH WIRES.

TRANSLATED BY SAMUEL H. NEEDLES.

[*Proceedings of the Academy of Sciences, of Paris, June 22, 1885. Note of M. Blavier, Presented by M. Mascart.*]

Several years ago, when the construction of extensive subterranean telegraph lines commenced, now connecting the principal cities of France and Germany, it was expected that their conductors would be entirely protected from atmospheric storms. Each wire being covered with guttapercha, and a number of them united in a cable, they are further shielded by an outer covering of iron wire wound around the whole, or by a continuous cast-iron tube; and it is well-known that a body, if surrounded by a metallic envelope and the latter in communication with the earth, will remain neutral, whatever may be the outer electric condition.

It has, however, been found that occasionally on the occurrence of thunder storms, there are produced, at the stations served by the subterranean wires, discharges of electricity, which cause sparks and even melt the fine protecting earth-wires (*paratonnerres*). These accidents are much more rare, and are less injurious than is the case with aërial wires, and do not seem to be of such nature as to interfere with transmission. They are always co-incident with

thunder storms, commencing in the open country at considerable distance from cities, where, in the latter case, the subterranean telegraph wires are protected by the network of water and gas pipes, *below* which they are placed.

Thus, for example, during a violent thunder storm, on March 9th last, midway between Belfort and Besançon, France, on the subterranean line uniting these two cities, there were noticed sparks at each of the most distant terminii, while in the two places named an atmospheric perturbation was scarcely perceptible. This phenomenon, apparently contrary to the theory of static electricity, can be explained, it would seem, either by electro-dynamic or electro-static induction. If the telegraphic cable is buried at but little depth in earth of imperfect conductivity—as frequently has happened on the lines laid—the outer covering of the wires acquires, under the influence of storm clouds (and while the telegraph wires themselves remain in a neutral condition)—a greater or less charge of electricity. At the moment of a flash of lightning this charge becomes suddenly free—or at least partially so—and flows into the earth, *following the outer covering* in opposite directions. In the first place, there must be developed in the interior wires two induced currents in contrary directions, the difference between which alone would act upon the apparatus at the extreme stations. It appears, however, that the effect resulting therefrom must be very slight, the more so because the free current being rapidly lost in the earth induction must be very limited.

A second effect is, that the discharge of electricity contained in the outer covering of the cable not being instantaneous, its electric potential rapidly decreases for a moment, however brief that instant may be. The free current reacts on the interior wires, which suddenly become charged with electricity of contrary descriptions at the points in communication with the earth (that is, through the protecting wires and apparatus at the extreme stations), causing phenomena such as those above indicated. The exterior charge, in flowing off immediately afterwards, produces contrary electric movement in the wires, which movement follows very closely the one first named, becoming confounded therewith, and in most cases neutralizing its effects. It is, therefore, only exceptionally that we have to record the influence of thunder storms upon subterranean telegraph lines.

As somewhat related to this subject, the following, from the proceedings of the Electrotechnic Society of Berlin, session of April 28th last, will prove interesting:

Professor Fœrster gave an account of some researches in cosmic and telluric electricity; he first cited the more recent experiments of Andries, Hoppe, Gerland and others on the origin of atmospheric electricity, and on the production of energetic tension, as shown in thunder storms. He then mentioned the theory of Edlund, respecting the influence of the rotation of the earth, considering the latter as a magnet, alluding also to the previous analogous ideas of Faraday, and finally to the opinions of William and Werner Siemens on the constitution of the sun and its electric action upon the earth. As proof and support of the latter views, the speaker cited the results obtained during the past five years in relation to the evidently electric character of a large portion of the phenomena observed in comets, and drew some conclusions therefrom permitting a better explanation of the peculiarities of the zodiacal light.

In conclusion, Professor Fœrster mentioned briefly the work of observation upon telluric currents made on German electric (subterranean) lines. It has been thereby proved that the slight, but regular, variations of these currents correspond exactly with the progressive movement of the earth considered as a magnet. These results are much more precise than those obtained at Greenwich, where lines quite short were used, and where the currents given by the terminal earth-plates showed relatively preponderating action.

## BOOK NOTICES.

PROPERTIES OF MATTER. By P. G. Tait, M. A., Sec. R. S. E., etc. Edinburgh. Adam and Charles Black. 1885.

The advent of a new text-book on a subject which is now attracting much attention, is sure to be welcomed by students in this country, as well as abroad, as an opportune arrival and is assured of a cordial reception from all who are familiar with the author's admirable style and perspicuity of expression.

Professor Tait's name is especially familiar to us by his association with Sir William Thomson in the joint production some years ago of a now classic work on physics, in which the various theories of the nature of matter which have been advanced from time to time are clearly set forth.

The subject of this elementary work forms, as the author tells us in his preface, "the introduction to the course of Natural Philosophy in Edinburgh University." * * * "The work is (with the exception of a few isolated sections) intended for the average student, who is supposed to have a sound knowledge of ordinary geometry, and a moderate acquaintance with the elements of algebra and of trigonometry."

"But he is also supposed to have—what he can easily obtain from the simpler parts of the first two chapters of Thomson and Tait's *Elements of Natural Philosophy*, or from Clerk-Maxwell's excellent little treatise on *Matter and Motion*,—a general acquaintance with the fundamental principles of *Kinematics of a Point*, and of *Kinetics of a Particle*."

The volume is a small one, comprised in 315 pages, divided into fourteen chapters, with an appendix, as follows:

Chapter I, Introductory. II, Some hypotheses as to the ultimate structure of matter. III, Examples of terms in common use as applied to matter. IV, Time and space. V, Impenetrability, porosity, divisibility. VI, Inertia, mobility, centrifugal force. VII, Gravitation. VIII, Preliminary to deformability and elasticity. IX, Compressibility of gases and vapors. X, Compression of liquids. XI, Compressibility and rigidity of solids. XII, Cohesion and capillarity. XIII, Diffusion, osmose, transpiration, viscosity, etc. XIV, Aggregation of particles.

The appendix contains: I, Hypothesis as to the constitution of matter. By Professor Flint, D. D. II, Extracts from Clerk-Maxwell's article, "Atom." III, Vitruvius on Archimedes' experiment. IV, Singular passage of the "Principia."

The book is fairly, though not profusely illustrated with diagrams, and the mathematical formulæ are by no means formidable. Although dealing largely with such well known properties of matter as gravitation, inertia, divisibility, etc., the well-informed reader will find these threadbare subjects treated in a novel and forcible manner, and no one can peruse the book carefully without gaining valuable information on all the topics treated of.

It is to be regretted that the second chapter on the "Structure of Matter" is so very brief, and therefore unsatisfactory. A popular exposition of Sir Wm. Thomson's "Vortex Atom Theory," would have been eminently appropriate and advantageous, and the subject of his profound address at the Montreal meeting of the British Association for the Advancement of Science, entitled "Steps Toward a Kinetic Theory of Matter," is not even alluded to. It is safe to say that this address has done more to enlighten students in America, in regard to the modern conception of the nature of matter, than any other thesis. With this exception, there is little room for adverse criticism, and the volume, as a whole, is entitled to be called a model text-book, it will fill a hitherto vacant niche on the shelves of the student's library, and will be found a convenient book of reference to the teacher.

The author states in his preface that it is his present intention to continue his series of text-books by similar volumes on *Dynamics*, *Sound* and *Electricity*, it is to be hoped that he will shortly carry out this plan, and thus complete a work which has been so well commenced. A. E. O., Jr.

THE LIFE OF JAMES CLERK MAXWELL. With Selections from his Correspondence and Occasional Writings. By Lewis Campbell, M. A., LL. D., and Wm. Garnett, M. A. London: Macmillan & Co.

This is a most charming book from its first to its last chapter. It is seldom that a great man is so fortunate in his biographers. In this case both gentlemen were his friends and associates in his scientific work. Anything which relates to the life of one who has done so much to enrich and continue the work of Newton and Faraday must have great interest to scientific students. Even the history of his youthful days, made up largely from a diary kept by his father, to whom he seems to have been much indebted for the development of his great mental powers, is full of interest. The greater portion of the book consists of correspondence between Prof. Maxwell and well-known scientific men, introduced in chronological order, with explanatory paragraphs by Mr. Campbell. Much valuable information in connection with his scientific researches is also contained in letters of a social character. Not the least attractive feature of the book is the insight which it gives us into the character of the *man*, whose every-day life was marked with an affectionate tenderness, large-heartedness and solicitude for the welfare of others, which is quite remarkable and which accounts for the love which all his associates bore to him and intensifies the regret that such a man should have been taken away before his time. E. A. S.

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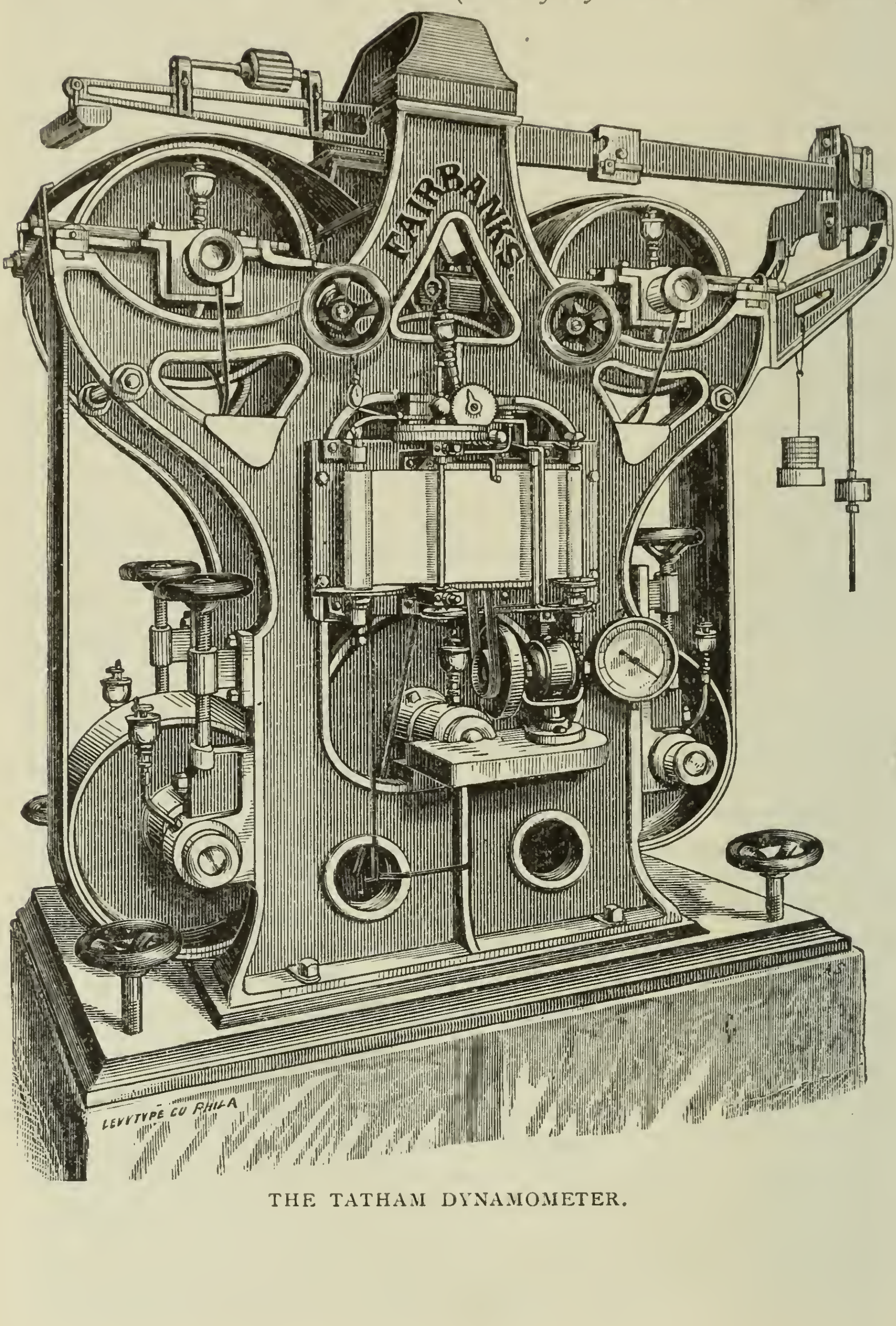
VARIATIONS OF THE SUN'S DIAMETER.—M. Hilfiker, of the Neufchâtel Observatory, states that the variability of the sun's diameter is very perceptible, the greatest diameters coinciding with the minimum period of sun spots, the least with the maximum. Similar conclusions had been previously indicated by Father Rosa, the colleague of Father Secchi.—*Les Mondes*, October 9, 1884.

DENSITY AND FIGURE OF THE EARTH.—The experiments of Cornu and Baille indicate a probable terrestrial density between 5·4 and 5·6, and they think that the result of Baily, 5·67, is too large. Cavendish, in 1798, estimated the mean density at 5·48. Reicle, in 1837, at 5·44. All of these results confirm, in a remarkable manner, the anticipations of Newton, who, in Book III. of the "Principia, Theorem 10," declared that the mean density of the earth must be between five and six times that of water. Gen. D. F. Menabrea has revised the experiments of Cavendish with the torsion balance, and found certain disturbances which were overlooked. Making proper allowances for those disturbances, he finds a mean value of 5·58. In a further investigation, he applied Ivory's theorem to the special case of an ellipsoid of revolution, supposed primitively fluid, but composed of concentric layers of different densities, deducing a flattening of $\frac{1}{293 \cdot 5}$. The most recent geodetic labors have shown that the terrestrial meridians are not all alike, and that consequently the earth is not a perfect ellipsoid. Moreover, there are singular anomalies at divers stations in the oscillations of the pendulum, which seem to show that the terrestrial mass is not distributed in uniform layers. These facts indicate the need of new investigations suitable for completing those of Cornu and Baille.—*Comptes Rendus*, February 16, 1885.

*Jour. Frank. Inst., Vol. CXX. Nov., 1885.*
(*Tests of Dynamo-Electric Machines.*)




THE TATHAM DYNAMOMETER.

# JOURNAL

OF THE

# FRANKLIN INSTITUTE

OF THE STATE OF PENNSYLVANIA,

FOR THE PROMOTION OF THE MECHANIC ARTS.

VOL. CXX. DECEMBER, 1885. No. 6.



## CYLINDER CONDENSATION IN STEAM ENGINES. AN EXPERIMENTAL INVESTIGATION.

BY CHAS. L. GATELY, M. E., AND ALVIN P. KLETZSCH, M. E.

[*Presented to the American Association for Advancement of Science; Ann Arbor Meeting, 1885, with an Introduction by* PROFESSOR R. H. THURSTON.]

[*Concluded from November Issue, page 346.*]

### CHAPTER IV.

#### 19. CALCULATION AND LAW OF CASE I.

The foregoing logs and Table No. 1 have reference to the experiments in which the cut-off was varied.

The experiments are four in number, and the apparent cut-off taken corresponded approximately to one-eighth, one-third, one-half, and five-eighths, these being deemed a sufficient number in order to permit of the forming of an expression containing the per cent. of cut-off as a variable.

From Table 1, it will be seen that the true cut-offs, as calculated from the card, are ·131, ·330, ·443 and ·589, corresponding respectively to the apparent cut-offs above mentioned. After averaging the logs and placing the same in suitable shape for use, the data

to be determined from the indicator-cards was calculated. For this purpose, blanks were ruled so as to contain:

The area of cards in square inches;
The real cut-off in inches;
The apparent cut-off in inches;
Pressure at cut-off in inches;
Pressure at release in inches;
Real volume at release in inches;
Length of indicator diagram in inches.

After averaging the results of each test for all the cards, both of the outer and inner cylinder, they were reduced to:

Mean effective pressure.

Per cent. of real and apparent cut-off per length of stroke and initial pressure of the steam in pounds per square inch on the piston and pressure of the steam in pounds on the square inch, at the opening of exhaust and their values entered in Table 1.

To determine the amount of condensation of steam in the steam engine cylinder, up to the point of cut-off, the difference was taken between the amount of water pumped into the boiler as calculated from the weir and the amount shown by the cards up to the point of cut-off. The ratio of this quantity to the true amount will be the per cent. of cylinder condensation up to the point of cutting off the steam. The method of deducing the amount of feed water pumped into the boilers as calculated from the thermal units of the weir will be described below. The meter readings in this case were of no account, for the reason already mentioned, namely, that three boilers were used while the meter indicated the amount for two of them. The per cent. of condensation, as determined, increases as the ratio of expansion increases.

*Plate I* will serve to show the final results more clearly. The ordinates representing per cent. of cut-off in length of stroke and the abscisses the amount of condensation expressed in per cent. of the total amount of steam furnished to the engine.

20. GENERAL METHOD OF CALCULATION AND OF DEDUCTION OF LAW OF CONDENSATION, WITH VARYING RATIOS OF EXPANSION—USE OF GRAPHICAL METHOD.

In the annexed table, will be found the observed data and the

calculated results of the experiments made with the engine, and in the manner precedingly described for variable cut-off.

(*See Table No. 1.*)

The experiments were four in number, and the results are arranged in parallel columns under their respective cut-offs, namely, ·589, 443, ·330 and ·131 of the length of the piston stroke. A smaller ratio of expansion could not well be obtained on account of the size of the boilers, these not being able to supply the demand for steam made upon them by the engine when subjected to a greater load.

For facility of reference, the quantities as far as practicable are arranged in groups, and the lines composing them numbered.

*Time.*—Lines 1 and 2 contain the date and time of beginning and concluding of each of the tests, and line 3, the duration in consecutive minutes.

*Total Quantities.*—Line 4 contains the number of double strokes made by the piston, obtained by subtracting the indications of the counter at the beginning from the reading at the completion of the test. Line 5 contains the total quantity of feed water pumped into the boilers, as calculated from the rise in temperature of the condensing water which flowed over the weir.

It is obtained by dividing the total number of heat units as calculated from the weir, together with the heat units due to radiation, and those converted into work by the heat units in one pound of the steam at the pressure of the boiler, corrected for the heat units due to the water of priming, minus the heat in one pound of the water of condensation. It will be seen, thus, that the weir, at least in this case, came in to good advantage, as without it and with insufficient meter readings, the tests in this case could certainly not have been used.

Line 6 contains the number of pounds of feed water pumped into the boilers per hour, and is found by dividing the total pounds of feed water on line 5 by the duration of the test in hours.

Line 7 gives the average height of the water flowing over the notch. By means of the partitions placed in the tumbling-bay and the perforations in the last one, the water passed in a steady flow under the pointer, attached to the micrometer screw, so that nothing interfered to ascertain the correct reading of the micrometer scale.

Line 8 are the number of double strokes made by the engine piston per minute, and are the quotients of the division of the quantities on line 4 by the quantities on line 3.

Line 9 is the observed vacuum in inches of mercury per gauge, and each test represents the average of the readings taken.

Line 10 contains the mean boiler pressure in pounds per square inch above the atmosphere, as per gauge.

Line 11 and 12 contain the steam pressure in the cylinder in pounds per square inch above absolute zero, or point of no pressure of the atmosphere, at the point of cutting off the steam and at the opening of release. Line 13 contains the mean gross effective pressure of the steam upon the face of the piston during its stroke. These quantities were taken from the indicator diagram. Those on lines 11 and 12, by direct measurement and then by multiplying them by the scale of spring used in the indicators during the test.

The mean gross effective pressures on line 13 were obtained by multiplying the average area of the cards in square inches by the scale of the spring used, and dividing the product by the average length of card taken. The area of the cards, in square inches, was obtained by means of J. Amsler-Laffon polar-planimeter, undoubtedly the best for its construction and accuracy, known to the present engineers.

Line 14 contains the pressure on the square inch required to work the engine by itself, and was obtained from the friction cards taken from the engine for this purpose.

Line 15 contains the mean net effective pressure in pounds per square inch on the piston, and is the difference between the quantities on lines 13 and 14.

Line 16 is the per cent. which the quantity on line 15 is of the quantity on line 13.

Line 17 contains the gross effective horse-power of 33,000 foot pounds raised one foot high, developed by the engine and calculated for the mean gross effective pressure on line 13, the number of double strokes on line 7 of each test and the distance travelled by the piston while making one stroke, namely, seven feet.

Line 18 contains the net horse-power usefully applied, and is calculated from the piston pressures on line 15, and for the speed of piston on line 8.

Line 19 contains the number of pounds of feed water consumed

per hour per gross effective horse-power. These weights are the quotient of the division of the quantities on line 6 by the quantities on line 17.

Line 20 contains the number of pounds of feed water consumed per hour per net effective horse-power, and is the quotient of the quantities on line 6 by the quantities on line 18.

*Temperatures.*—Line 21 contains the average temperature of the injection water. This was nearly constant for each test, owing to the large body of water from which it was drawn and to the depth of the pipe below the ground.

Line 22 contains the average temperature of the weir during each trial. No difficulty whatever was experienced in obtaining this temperature, when holding the thermometer in the water where leaving the notch, allowing it to strike the bulb. Thus, giving at the same time not only the true reading, but also preventing an undue eddy being produced in the weir, which would have affected the readings of the micrometer scale taken at the same time. Line 23 contains the temperatures of the feed water, taken after the water had left the meter. Sufficient water was allowed to pass through the meter in order not to be affected by direct connection with the pipe, etc. This temperature was usually taken while the water was fed to the boilers used in the trials. As far as the third boiler would permit a continual stream was fed into the boilers, in order to keep the boilers as much as possible at the same level.

Line 24 contains the per cent. of the amount of feed water that passed into the cylinder from the boilers, in the form of water, entrained in the steam, due to incomplete evaporation. The following is the method in detail in which these tests were made, and the manner of arriving at the result:

The weight of the calorimeter empty was first taken. Seventy pounds of water of known temperature $t''$, was then introduced, this being a convenient figure to handle, and about the capacity of the tank. The three-way cock connecting the worm of the calorimeter with the pipe leading to the boiler was then opened, and steam allowed to flow into the air until the connections were of the same temperature as the steam, and the time of flow noted. The cock was then turned, and the steam flowed into the calorimeter, heating the seventy pounds of condensing water $= W$ up

to any observed temperature $t'$, the whole volume of water being well agitated, so as to equalize the temperature. The time of the latter flow was noted and the boiler pressure recorded.

Let $W$ = the weight of condensing water;
$w$ = the weight of wet steam;
$t''$ = initial temperature;
$t'$ = final temperature;
$R = t' - t''$ = range of temperature;
$t$ = heat units in one pound of water at the boiler pressure;
$x$ = steam run into calorimeter;
$U = W \times R$ = heat units transferred to calorimeter;
$H = T - t'$ = heat from steam;
$h = t' - t''$ = heat from water;
$y$ = percentage of priming; we then have Dr. Thurston's equation*

$$Hx + h\,(w - x) = U.$$

And solving for $x$

$$x = \frac{U - hw}{H - h} : \quad y = \frac{w - x}{w}.$$

The time of flow in air and in the calorimeter is given so as to calculate the amount to be deducted from the feed water reading, due to loss from this cause. Thus, in Test 1, flow in air, 1 minute; in calorimeter, 2½ minutes. We see that the weight which flowed into the calorimeter in this time is 5⅜ pounds, or 2·15 per minute; therefore, 3½ times 2·15 will give the total amount to be subtracted in this case = 7·525 pounds, nearly. The heat units, in all cases, were interpolated from Porter's tables.

Line 25 contains the total number of pounds of steam in the cylinder up to the point of cutting off the steam. It is calculated for the weight of one cubic foot of steam at the pressure of cut-off, as given in Porter's tables, into the piston displacement, due allowance being made for clearance and piston rod. Thus, if $W$ = total number of pounds of steam at cut-off, we would have, for one end,

$$W = (V\,C + V')\,N\,w\,T$$

where $V$ = volume of the end of cylinder in cubic feet.

*American Institute Report on Steam Boilers, 1871, p. 17.

$V'$ = clearance of the end in question;
$N$ = number of revolutions per minute;
$C$ = per cent. of stroke at which steam is cut off;
$w$ = weight of one cubic foot of the steam in decimals of a pound, corresponding to the average pressure in the cylinder; and
$T$ = duration of trial in minutes.

The weight of the steam thus calculated was evaporated from and at the temperature of the feed water.

Line 26 contains the number of pounds of steam in the cylinder at cut-off at the end of one hour, and calculated from the pressure in the cylinder at the point of cutting off the steam. It is the quotient of the division of the quantities on line 25 by the duration of the trial expressed in hours.

Line 27 contains the total pounds of steam in the cylinder at release, calculated from the pressure of the steam in the cylinder, immediately before the opening of the exhaust. The calculation is in all respects similar to the calculations of line 25, substituting for $c$ the length of stroke completed up to the opening of the exhaust.

Line 28 contains the total number of thermal units in the steam as calculated from the feed water consumed. As the total number of thermal units passed into the engine is the sum of the quantities of the heat expended, we have for the whole number of thermal units: the thermal units shown at exhaust plus the number due the energy expended in driving the engine, and its controlling apparatus plus that due to radiation and conduction. The quantities in line 28 are the sum of these three forms of expended heat.

Line 29 contains the total number of heat units accounted for by the weir. Knowing the average height of flow over the notch board, the number of cubic feet of water which have passed through the condenser can easily be calculated by means of the usual formula.

$$Q = \tfrac{2}{3}\, c\, b\, h \sqrt{2\, g\, h}$$

or, when $c$ and $b$ are known, as in this case, then

$$Q'' = 1{\cdot}6673\, h^{\frac{3}{2}}$$

where $Q$ = flow in cubic feet per second;
$h$ = average height of water in inches over notch;

$b$ = breadth of notch in inches;
$c$ = coefficient of contraction.

Substituting for $h$ the average height determined as per experiment, and multiplying by the time of flow in seconds, the number of cubic feet are determined at the temperature of the trial. Knowing the weight of one cubic foot of water at the temperature given by the weir, and the thermal units in one pound of the water at the temperatures of the weir and injection, the thermal units in line 29 are easily determined. Let $Q$ as before represent flow in cubic feet per second.

$T$ = duration of test in seconds;
$W$ = weight of one cubic foot of the condensing water and wet steam;
$H$ = heat units in one pound of the condensing water at the final temperature, and
$h$ = heat units in one pound of the injection water, then
$B\ T\ U$ the total units of heat contained on line 29 becomes

$$B\ T\ U = Q\ T\ W(H - h).$$

Line 30 contains the total number of thermal units as per weir per hour. It is the quotient obtained by the division of the quantities on line 29 by the duration of the trials in hours.

Line 31 contains the per cent. of the steam evaporated in the boilers, not accounted for by the indicator at cut-off. Line 6 giving the water actually consumed per hour by the engine, and line 26 being the amount indicated by the diagrams, the difference is the amount not accounted for by the indicator, existing in the form of water in the cylinder. The per cent. which the quantity is of line 6, is the amount of condensation in the steam engine cylinder, to the point of cutting off the steam.

Knowing the percentage of condensation for the various ratios of expansion as determined in these trials, and in order to readily determine the amount of condensation for other points of cut-off, the results have been plotted, the locus of the curve showing the per cent. of cylinder condensation for the ratios of expansion under which the engine may be run. (*Plate I.*)

### 21. CALCULATIONS IN DETAIL—RESULTS DISCUSSED AND CLASSIFIED—FINAL EXPRESSIONS AND CURVES REPRESENTING THEM.

On examining Table 1, it will be found that the conditions

CASE I.—CONDENSING.—VARIABLE CUT-OFF.

*Table No. 1.*—Containing the Data and Results of Experiments made at Sandy Hook, Conn., to determine the Laws of Cylinder Condensation.

| Number of Line. | | | | Fraction of the Stroke of Piston completed when Steam was Cut off. | | | |
|---|---|---|---|---|---|---|---|
| | | | | ·589 | ·443 | ·330 | ·131 |
| 1 | Time. | | Date of commencing experiment, | A. M. 11·32, May 25. | P. M. 2·04, May 25. | P. M. 2·36, May 24. | A. M. 10·16, May 24 |
| 2 | | | Date of ending experiment, | P. M. 1·02, May 25 | P. M. 4·04, May 25. | P. M. 4·31, May 24 | P. M. 12·16, May 24. |
| 3 | | | Duration of experiment in consecutive minutes, | 90 | 120 | 115 | 120 |
| 4 | Total Quantities. | | Number of double strokes made by the engine piston, per counter, | 6144 | 8095 | 7741 | 8274 |
| 5 | | | Number of pounds of feed water pumped into boilers, per weir, | 8788·5 | 10222·4 | 7331·5 | 3375·5 |
| 6 | | | Number of pounds of feed water pumped into boilers, per weir, per hour, | 5859 | 5111·2 | 3825·1 | 1687·75 |
| 7 | | | Average height of water over weir, in inches, | 4·474 | 4·161 | 3·195 | 2·2702 |
| 8 | Engine | | Number of double strokes made per minute by the engine piston, | 68·26 | 67·45 | 67·32 | 68·95 |
| 9 | | | Vacuum in condenser in inches of mercury, per gauge, | 21·45 | 22·06 | 20·95 | 22·01 |
| 10 | STEAM PRESSURES | In Cylinder per Indicator. | In pounds per square inch above atmosphere in boilers, per gauge, | 56·83 | 61·28 | 6[illegible]·1 | 61·1 |
| 11 | | | In pounds per square inch above zero at cutting off the steam, | 61·54 | 68·34 | 62·10 | 40·11 |
| 12 | | | In pounds per square inch above zero at release, | 38·28 | 32·03 | 21·[illegible]5 | 8·47 |
| 13 | | | Mean gross effective pressure in pounds per square inch on piston. | 47·94 | 47·11 | 36·03 | 19·36 |
| 14 | | | Pressure in pounds on the square inch required to work the engine, | 3·5 | 3·5 | 3·5 | 3·5 |
| 15 | | | Mean net effective pressure in pounds per square inch on piston during its stroke, | 44·44 | 43·61 | 32·53 | 15·86 |
| 16 | | | Per cent. of which the mean net effective pressure is of the mean gross effective pressure, | 92·69 | 92·57 | 9[illegible]·16 | 81·92 |
| 17 | POWER. | Absolute. | Gross effective horses-power, developed by the engine, | 174·589 | 169·474 | 129·420 | 52·158 |
| 18 | | | Net horses-power, usefully applied, | 162·82 | 156·88 | 116·695 | 42·725 |
| 19 | | Economic | Pounds of feed water consumed per hour, per gross effective H. P. | 33·55 | 30·16 | 29·55 | 32·35 |
| 20 | | | Pounds of feed water consumed per hour, per net effective H. P., | 35·98 | 32·58 | 32·78 | 39·49 |
| 21 | Temperature in Deg. Fahr. | | Of the injection water, | 69· | 67·7 | 71·6 | 67·1 |
| 22 | | | Of the water in the weir, | 131·9 | 131·44 | 135·7 | 110·3 |
| 23 | | | Of the feed water, | . . . . | 114· | 140 | 114·3 |
| 24 | | | Per cent. of the amount of feed water, that passes into the cylinder from the boilers in the form of water entrained in the steam, due to incomplete evaporation, | 5·22 | 5·68 | 7·86 | 7·69 |
| 25 | | | Total pounds of steam in the cylinder at cut-off, calculated from the pressure of the steam in the cylinder at the point of cut-off, | 6790·251 | 7454·477 | 4847·418 | 1685·159 |
| 26 | | | Pounds of steam in the cylinder at cut-off, calculated from the pressure of the steam in the cylinder at the point of cut-off at the end of one hour, | 4526·834 | 3727·24 | 2529·24 | 842·579 |
| 27 | | | Total pounds of steam in the cylinder at release; calculated from the pressure of the steam in the cylinder at release, immediately before the opening of exhaust, | 6902·309 | 7805·352 | 5049·612 | 2288·183 |
| 28 | | | Total number of thermal units in the steam expended by the engine, as calculated from the feed water consumed, | 9031477·5 | 10481821·8 | 7340163· | 3451899·8 |
| 29 | | | Total number of thermal units, as per weir, | 7920754·6 | 9113387·6 | 6354643·1 | 3018080·5 |
| 30 | | | Total number of thermal units, as per weir, per hour, | 5280503· | 4556694· | 3631225 | 1509040· |
| 31 | | | Per cent. of the steam evaporated in the boilers, not accounted for by the indicator at cut-off, | 22·73 | 27·08 | 33·87 | 50·07 |

intended to have been kept constant during the trials vary somewhat.

The distances travelled by the engine piston in the tests of Case I, does not vary more than seven feet per minute from the average and the difference between the greatest and lowest speed during the trials amounts to but thirteen feet per minute. When taking into account the controlling power of the engine, the degree with which the pulley heated and consequent expansion of its rim a fluctuation of from one to two and a-half per cent. at the greatest could, with the limited amount of time and assistance, hardly be avoided. The steam pressures as recorded per boiler gauge also show some fluctuation; this, however, was not due to any inexperience in firing, but to the greater demand made by the engine upon the boilers than these were originally intended for. As the work of the engine came down to its ordinary conditions; that is, to the capacity of the boilers, a more uniform boiler pressure was obtained, varying not more than one and a-half per cent. between the highest and lowest pressures, while the difference in the whole range amounts to but five per cent. of the highest boiler pressure recorded. As shown in our later tests, condensation changing slowly with the initial pressures, the difference due to a slight variation of the boiler pressure, would not appreciably affect the law of condensation at the varying cut-offs of ·589 and ·443, respectively.

Having discussed the two constant factors and their slight variation during the tests of Case I, the per cent. of cut-off per length of stroke, and the amount of condensation, can now be taken into consideration.

From Table No. 1, we have for a

| | | |
|---|---|---|
| Cut-off of ·589; | cylinder condensation | = 22·73 per cent. |
| ·443; | | = 27·08 |
| ·330; | | = 33·87 |
| ·131; | | = 50·07 |

from which we see that the condensation increases rapidly with expansion of steam; or, in other words, with longer exposure of the sides of the cylinder, cylinder head and piston, to the decreasing temperatures of the expanding steam.

Plotting these results upon paper and making the abscisses represent the amount of condensation, or the per cent. of the total steam condensed in the steam engine cylinder, excepting that due

to the priming, and letting the ordinates represent the fraction of the stroke completed when the steam was cut off, and tracing the curve through the points of intersection we obtain the curve as represented in *Plate I.*

22. METHOD OF DEDUCING ALGEBRAIC EXPRESSIONS FOR VARIATION OF CONDENSATION IN CASE I, AND FUNCTIONS OF SIZE OF ENGINE AND AREA OF SURFACE EXPOSED.

Taking the actual figures in Table 1, as found by experiment for cut-off and cylinder condensation, and an intermediate point from the curve between the cut-offs of ·131 and ·330, we have for

| | |
|---|---|
| Cut-off $= y =$ ·131 | condensation $= x \doteq 50·$ |
| ·225 | $= 41·$ |
| ·33 | $= 34·$ |
| ·45 | $= 27·$ |
| ·59 | $= 22·5$ |

The locus of these points appearing to follow an hyperbolic expression, we applied the general equation of an hyperbola.

$$(x + a)(y + b) = c, \text{ or}$$
$$xy + bx + ab = c.$$

Transposing, we have

$$bx + ay - c = -xy,$$

and substituting the above values for $x$ and $y$, we have

$$50\,b + ·13\,a - c = -·0650 \qquad (1)$$
$$34\,b + ·33\,a - c = -·11225 \qquad (2)$$
$$22·5\,b + ·59\,a - c = -·13275 \qquad (3)$$

Equating (1) and (2) and eliminating $c$, we have

$$·16\,b - ·20\,a = ·04725 \qquad (4)$$

and performing the same operation with equation (1) and (3), we have

$$·275\,b - 46\,a = ·06775 \qquad (5)$$

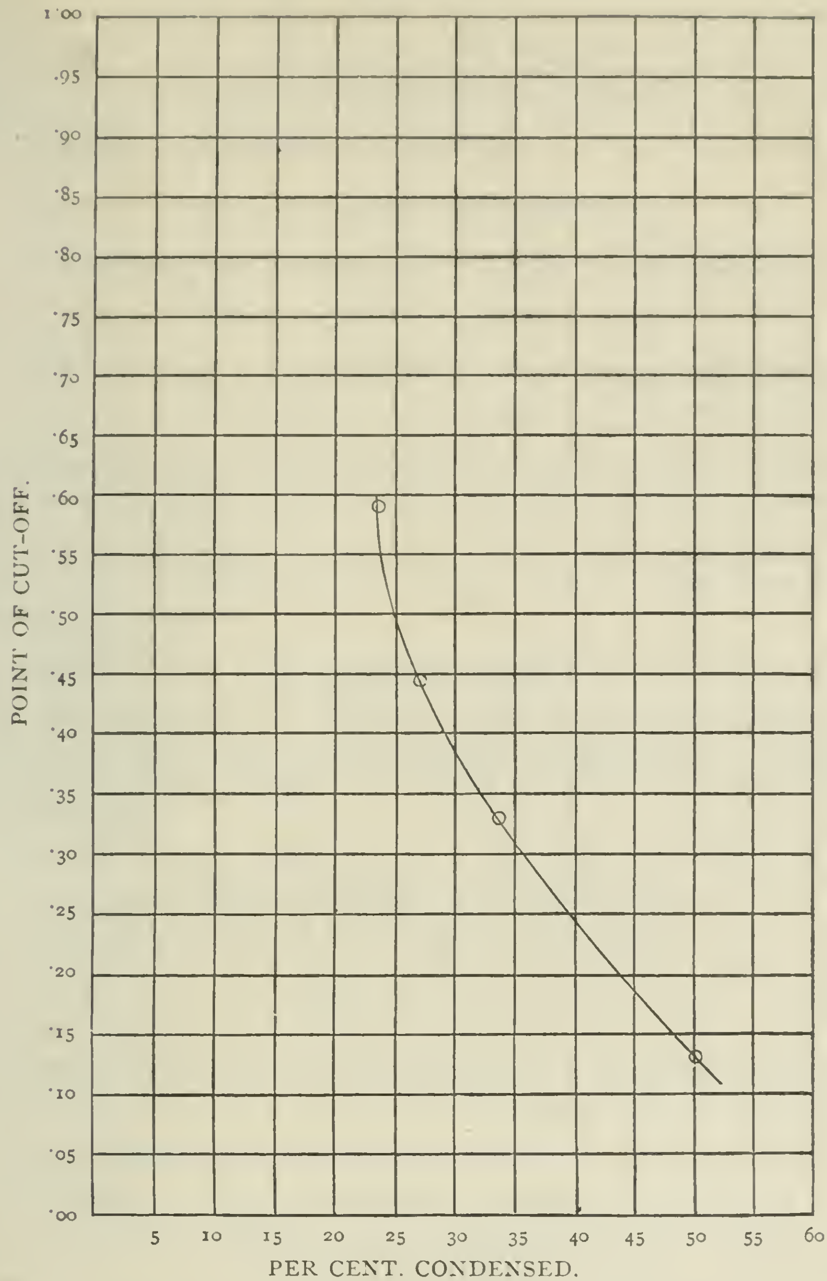
We now have two equations with two unknown quantities, eliminating $a$ from these by the ordinary rules of algebra, we have

$$·0186\,b = ·008185$$
$$b = 44005$$

Substituting the value of $b$ in (4), we have

$$·0704 - ·20\,a = ·04725$$
$$·20\,a = ·02315$$
$$a = ·11575$$

PLATE I.




CONDENSATION WITH BOILER PRESSURE VARIABLE.

and by substituting the values for $a$ and $b$ in (1), we have

$$\cdot 22 + 0150475 - c = - \cdot 0650$$

$$\text{and } c = \cdot 3000475$$

As the values of $a$, $b$ and $c$, when calculated by the other of the original equations, differ only in the fifth and sixth decimal places from the results obtained above, these values for the

coefficients of $x$ and $y$ in the hyperbolic equation, and of the constant may be taken as their true values, thus determining experimentally the law of cylinder condensation as a function of the ratio of expansion. We thus have the following values for $a = 0{\cdot}11575$, $b = 0{\cdot}44005$ and $c = 0{\cdot}3000475$, in accordance with which we will take

$$a = 0{\cdot}12 ; \; b = 0{\cdot}44 ; \; c = 0{\cdot}3$$

and substituting these values in the general case, we have

$$x\,y + 0{\cdot}44\,x + 0{\cdot}12\,y = 0{\cdot}3 \qquad A.$$

We now test equation $A$, by substituting $y = {\cdot}13$, $0{\cdot}225$, $0{\cdot}33$, etc., and computing the values for $x$, we thus find,

| | | |
|---|---|---|
| $y$ = cut-off = 0·13 ; | $x$ = cylinder condensation = 0·499 ; | error of — 0·001 |
| = ·225 ; | = 0·410 ; | 0·000 |
| = ·33 ; | = 0·338 ; | — 0·002 |
| = ·45 ; | = 0·274 ; | + 0·004 |
| = ·59 ; | = 0·222 ; | + 0·002 |

This equation then satisfies so closely the results obtained by direct observation, that it may be taken to represent the law of condensation, as a function of the cut off for this engine under the conditions used. It is the equation of an hyperbola and may be put under the form,

$$(x + 0{\cdot}12)\,(y + 0{\cdot}44) = {\cdot}2472 \qquad B$$

or if $x' = x + 0{\cdot}12$ and $y' = y + {\cdot}44$

we have

$$x'\,y' = 0{\cdot}2472$$

which is the equation of an hyperbola referred to its asymptotes.

Discussion of the equation.

In the equation $A$, if the cut-off be zero, then $y = 0$, and $x = {\cdot}3 \pm 44 = {\cdot}68$ or nearly seventy per cent. of the steam will be condensed in the cylinder when the cut-off is the least possible.

If we allow steam to follow full stroke, $y = 1{\cdot}0$, and we find $x = {\cdot}12$, or at full stroke twelve per cent. of the steam will be condensed in this engine. These latter conclusions are, however, of less value, because they result from extending an empirical formula too far beyond the limits of the experiments, or which it is founded in both directions.

As a matter of curiosity, we notice that equation $B$ shows that when the cut-off is — 0·44, the condensation will be infinite.

Cylinder condensation as function of area exposed. The area of cylinder surface exposed to the action of the initial steam varying directly as the cut-off, we obtain from the curve of *Plate I*, when allowing $z$ to represent the area in square feet of the cylinder, and its piston exposed to the steam, for a

| | | |
|---|---|---|
| Cut-off of ·6; | square feet of area exposed | $= z =$ 13·86 |
| ·5; | | $= z =$ 12·21 |
| ·4; | | $= z =$ 10·56 |
| ·3; | | $= z =$ 8·91 |
| ·2; | | $= z =$ 7·26 |
| ·1; | | $= z =$ 5·61 |
| ·0; | | $= z =$ 3·96 |

Plotting these, as in *Plate II*, making the ordinates the fraction of stroke completed, when steam is cut off; and the abscisses the area in square feet exposed to the initial steam, corresponding to these cut-offs, we find the locus of the points to be a straight line, whose equation is,

$$x = 3{\cdot}96 + 16{\cdot}5\,z;$$

that is, the area exposed to the action of the steam varies directly as the cut-off, as it should, as increase of admission increases the surface exposed.

From the above conclusion, we consequently infer that the amount of condensation expressed as some function of the area of surface exposed, must follow the same general law. The constants of the equation representing this law, are determined in precisely the same manner as were the constants in the equation representing the law of cylinder condensation, in which the cut-off per length of stroke is the variable function.

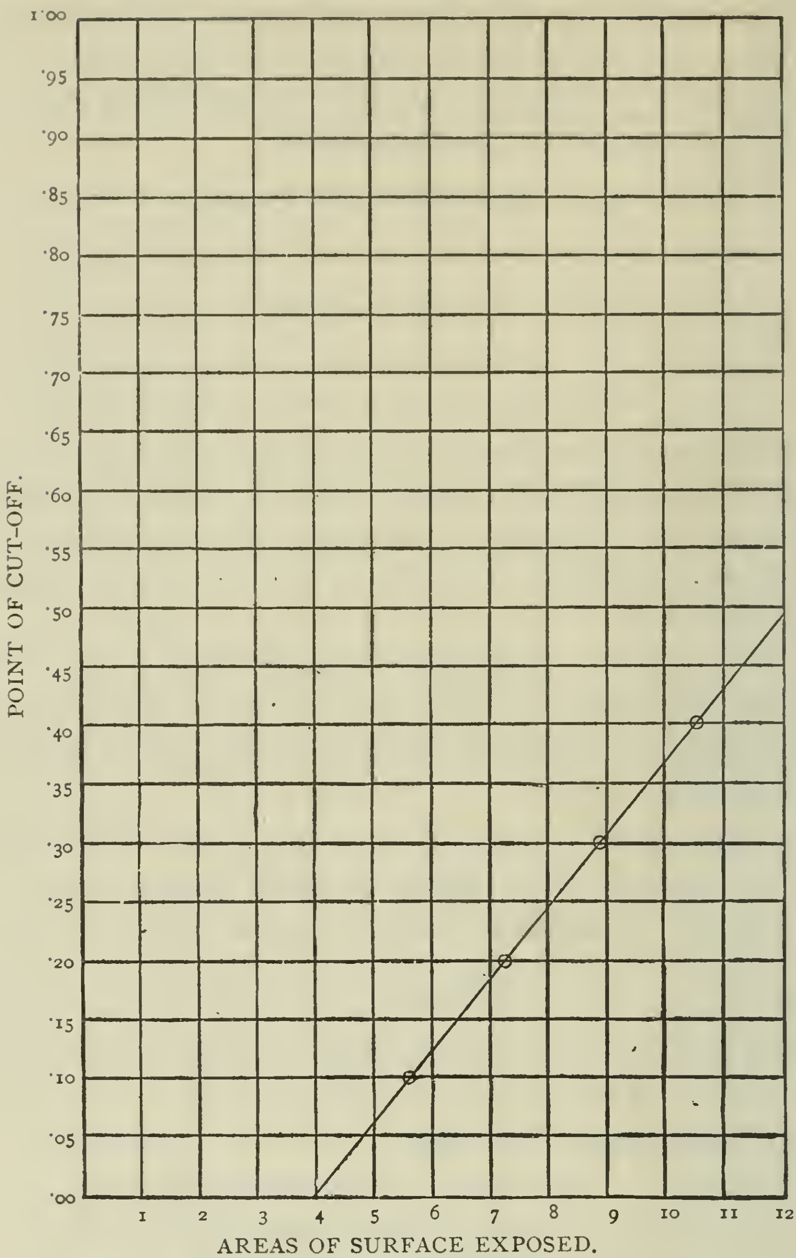
From *Plates I* and *II*, we have

letting $x =$ per cent. of condensation, as before,
$y =$ cut-off per length of stroke,
and $z =$ area of surface exposed:

| | | |
|---|---|---|
| $x =$ 22·4; | $y =$ ·6; | $z =$ 13·86 square feet. |
| 25· ; | ·5; | 12·21 |
| 28·5; | ·4; | 10·56 |
| 36· ; | ·3; | 8·91 |
| 44· ; | ·2; | 7·26 |
| 53·5; | ·1; | 5·61 |
| 68·1; | ·0; | 3·96 |

and representing the ordinates for this new curve by the value of

PLATE II.




CONDENSATION WITH VARIABLE AREAS EXPOSED.

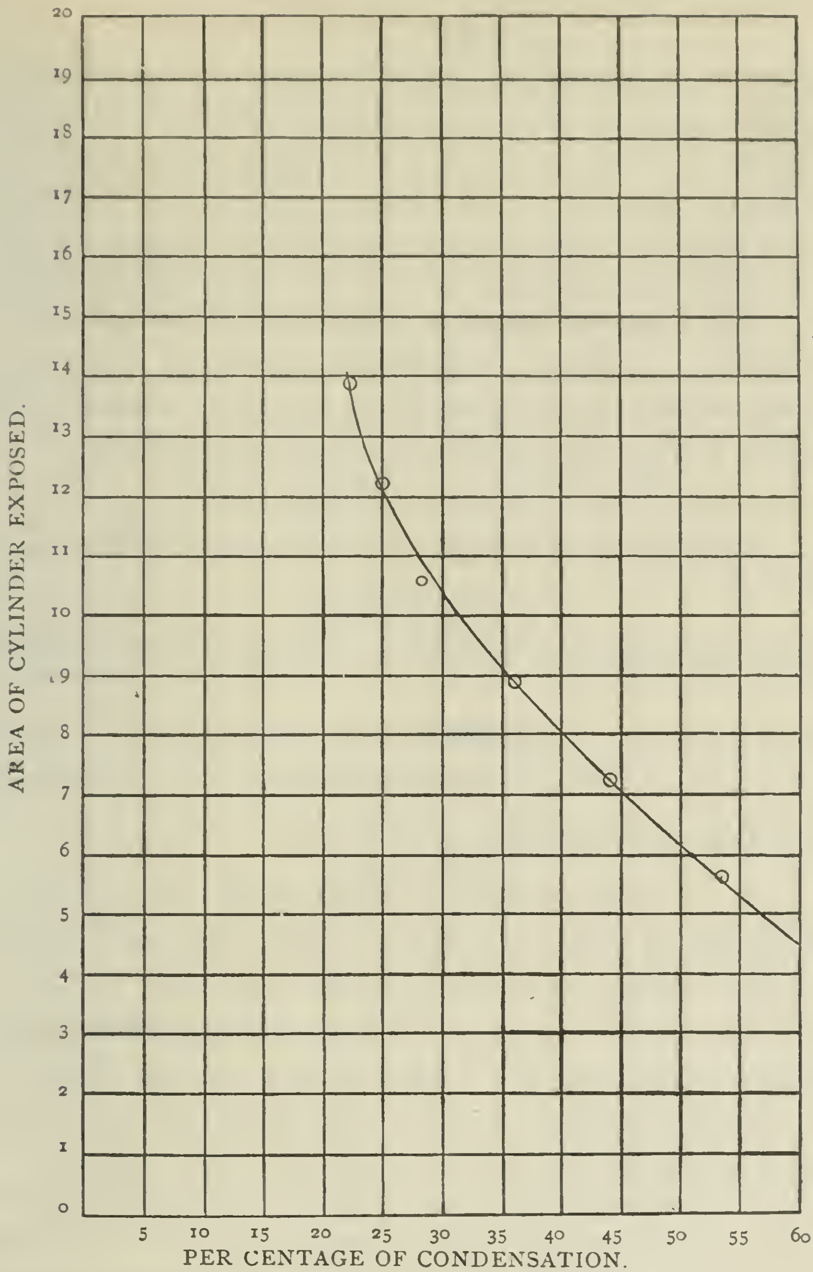
$z$, and the abscisses the corresponding cylinder condensation, we find the locus of the curve, represented on *Plate III*, to have the same general appearance of the curve of *Plate I.*

We infer consequently that it follows the general law, the equation of which for this case is,

$$xz + bx + az = c \qquad C.$$

$x$ and $z$ being the two variables, mentioned above.

PLATE III.




CONDENSATION WITH VARIABLE AREAS EXPOSED.

Transposing, eliminating and substituting, as in the first application of the general formula, we find for the values of the constants,

$$a = -4{\cdot}77\,;\ b = -1{\cdot}026\,;\ c = 221{\cdot}36,$$

and these values substituted in equation $C$, gives

$$xz - 1{\cdot}026 \times - 4{\cdot}77\, z = 221{\cdot}36 \qquad D.$$

By substituting the values of $z$, and calculating for $x$, we find when

| | | |
|---|---|---|
| $z = 13{\cdot}86$; | $x$ = cylinder condensation = 22·01; | error of — 0·39 |
| 12·21; | 25·00; | ± 0·000 |
| 10·56; | 28·50; | ± 0·000 |
| 8·91; | 33·50; | — 2·50 |
| 7·26; | 41·06; | — 2·94 |

This equation then satisfies the results obtained by experiment so closely, that it may be taken to represent this law of condensation as a function of the area exposed in square feet in this engine, to the action of the steam during the set of trials made for Case I. The equation is that of an hyperbola and may be written,

$$(x - 4{\cdot}77)\,(z - 1{\cdot}0266) = 216{\cdot}47 \qquad D.$$

or if $x' = x - 4{\cdot}77$, and $z' = z - 1{\cdot}026$

we have

$$x'\,z' = 216{\cdot}47$$

which is the equation of an hyperbola referred to its asymptotes.

23. COMPARISON WITH EXPERIMENT AND VERIFICATION OF FORM OF FUNCTION AND CONSTANT.

Substituting in equation $A$, which is,

$$x\,y + {\cdot}44\,x + {\cdot}12\,y = {\cdot}3,$$

the different values of $y$ = fraction of stroke completed up to cut-off, we have shown how nearly the calculated results corresponded with those obtained by direct experiment as given by the abscisses of the curve of *Plate I*, thus proving within what limits the equation is correct, and at the same time affords means of comparison as given by other authors upon this subject.

Dr. R. H. Thurston, in his paper on the "Theory of the Steam Engine" (J.F.I., 1884), concludes from the experiments of Mr. Isherwood that cylinder condensation varies sensibly as the square root of the ratio of expansion and that the amount of such condensation usually lies between one-tenth and one-fifth of the square root of that ratio, if estimated as a fraction of the quantity of steam demanded by a similar engine having an unjacketed cylinder.

Therefore, substituting in the general formula,

$$x = a\sqrt{r}$$

in which,

$x$ = per cent. of condensation
and $r$ = ratio of expansion,

the values of $a$ and $r$ and solving for the former, we should obtain, according to Professor Thurston, values for $a$ lying between one-fifth and one-tenth. Taking the values of *Plate I*, and substituting the values of $r$, when the cut-off is 0·15, we have for the ratio of expansion 6·6666 +, and for the per cent. of condensation 48·25, and these values in

$$a = \frac{x}{\sqrt{r}}$$

gives us

$$a = \frac{48 \cdot 25}{\sqrt{6 \cdot 6666}} = \frac{48 \cdot 25}{2.58} = \cdot 187.$$

Substituting for cut-off at ¼ when $r = 4 \cdot$, and solving, we have

$$a = \cdot 1987 +$$

Substituting for cut-off at ·35 when $r = 2 \cdot 8571$, and solving, we have

$$a = \cdot 1923 +$$

Substituting for cut-off at ·45 when $r = 2 \cdot 2222$ and solving, we have

$$a = \cdot 1812$$

Substituting for cut-off at ·55 when $r = 1 \cdot 8182$ and solving, we have

$$a = \cdot 174$$

Summarizing, we have

| | | |
|---|---|---|
| when $r = 6 \cdot 66\ +$ ; | | $a = 0 \cdot 187$ |
| $r = 4 \cdot 00$ | ; | $a = 0 \cdot 1987$ |
| $r = 2 \cdot 857$ | ; | $a = 0 \cdot 1923$ |
| $r = 2 \cdot 222\ +$ | ; | $a = 0 \cdot 1812$ |
| $r = 1 \cdot 82$ | ; | $a = 0 \cdot 174$ |

From which it will be seen that the values of $a$ lie between one-tenth and one-fifth and are almost equal to one-fifth in nearly all the tests to which the equation was applied, showing that, as Professor Thurston predicted, several years ago, the amount of cylinder condensation lies between one-tenth and one-fifth of the square root of the ratio of expansion, and that the results of this case, with variable ratio of expansion, very nearly coincide with those of Mr. Isherwood.

## CHAPTER V.

### 23. CALCULATION AND LAW OF CASE II.

In this case, as in the preceding, great care was taken to secure similar constant conditions in all the trials, and to maintain them as far as circumstances would permit. The logs containing the data of Case II will be found in Chapter III. Table 2 contains the data classified and the calculated results of the experiments made upon the engine used, to determine the effect of the boiler pressure upon condensation of steam in the steam engine cylinder. The experiments were five in number, though four of them only so fall within range as to permit of an expression being formed to represent the law of condensation.

The pressures used for the different trials are 80·0, 65·85, 52·33, 37·0 and 22·3; the real cut-off was taken at one-fifth, though the average is ·222, this being due to the third and fifth tests of this set, the others being nearly constant. The speed under which the tests were run, was kept as constant as the controlling mechanism permitted. The average is 69·6 revolutions, the greatest difference of any two of them is 3·6 revolutions, and the greatest difference between the average and the fastest speed amounts to 2·1 revolutions. The calculations for Case II were in all respects similar to those of Case I. Though the meter readings are given, the feed water consumed is calculated from the weir, this probably giving the more correct value.

### 24. GENERAL METHOD OF CALCULATION AND OF DEDUCTION OF LAW OF CONDENSATION, WITH VARYING RANGE OF PRESSURE.

In the annexed table, will be found the data and results as already mentioned in the last article.

(*See Table No.* 2.)

The experiments are five in number and are arranged under their respective boiler pressures of 80·0, 66·85, 52·33, 37·0 and 22·3 pounds to the square inch. This number was deemed sufficient to obtain an expression for cylinder condensation as a function of the boiler pressure. They are also within range of those used in every-day practice, especially in the type of engine used for our experiments. For facility of reference, the experiments are ranged in groups and the lines composing them numbered.

## Case II.—Condensing.—Variable Boiler Pressure.

*Table No. 2.*—Containing the Data and Results of Experiments, made at Sandy Hook, Conn., to determine the Laws of Cylinder Condensation.

| Number of Line. | | | Variable Steam Pressures of the Boilers. | | | | |
|---|---|---|---|---|---|---|---|
| | | | 80·0 | 66·85 | 52·33 | 37·0 | [illegible] |
| 1 | Time. | Date of commencing experiment, | A. M. 8·07, May 26. | A. M. 10·38, May 26. | P. M. 2 54, May 26. | A. M. 7·36, May 27. | A. M. 10·15, May |
| 2 | | Date of ending experiment, | A. M. 10·07, May 26. | P. M. 12·23, May 26. | P. M. 4·54, May 26. | A. M. 9·36, May 27. | P. M. 12·27, May 27. |
| 3 | | Duration of experiment, in consecutive minutes, | 120 | 105 | 120 | 120 | 120 |
| 4 | Total Quantities. | Number of double strokes made by the engine piston, per counter, | 8282 | 7426 | 8608 | 8270 | 8151 |
| 5 | | Number of pounds of feed water pumped into the boilers, per weir, | 6413·5 | 6026·4 | 5505·2 | 3723·9 | 2875·2 |
| 6 | | Number of pounds of feed water pumped into the boilers, per weir per hour, | 3206·75 | 3444·8 | 2752·6 | 1861·95 | 1437 6 |
| 7 | | Average height of water over weir, in inches, | 3·8691 | 3·4516 | 3·4154 | 3·0518 | 2 464[illegible] |
| 8 | Engine. | Number of double strokes made per minute by the engine piston, | 69·016 | 70·72 | 71·73 | 68·91 | 67·9[illegible]5 |
| 9 | | Vacuum in condenser in inches of mercury, per gauge, | 22·44 | 22·25 | 22·44 | 22·69 | 23· |
| 10 | | Fraction of stroke of piston completed when steam was cut off (apparent). | ·186 | ·184 | ·223 | ·188 | [illegible] |
| 11 | | Fraction of stroke of piston completed when steam was cut off (real), | ·208 | ·206 | ·244 | ·2102 | ·242 |
| 12 | Steam Pressures In Cylinder per Indicator. | In pounds per square inch above zero, at cutting off the steam, | 78·80 | 66·89 | 53·21 | 39·83 | 26·74 |
| 13 | | In pounds per square inch above zero. at release, | 18 08 | 15·53 | 14·34 | 9·80 | 7·96 |
| 14 | | Mean gross effective pressure in pounds per square inch on piston during its stroke, | 36·59 | 29·55 | 25·29 | 16 02 | 10·32 |
| 15 | | Pressure in pounds per square inch required to work the engine, | 3·5 | 3 5 | 3 5 | 3·5 | 3·5 |
| 16 | | Mean net effective pressure in pounds per square inch on piston during its stroke, | 33·09 | 26·05 | 21 79 | 12·52 | 6·82 |
| 17 | | Per cent. of which the mean net effective pressure is of the mean gross effective pressure, | 90 43 | 88·15 | 86·16 | 78 15 | 66 09 |
| 18 | Power. Absolute. | Gross effective horses-power developed by the engine, | 134·405 | 111·86 | 96·533 | 58·808 | 37·34[illegible] |
| 19 | | Net effective horses-power usefully applied, | 121·542 | 98 604 | 83· 73 | 45·958 | 24 08 |
| 20 | Power. Economic. | Pounds of feed water consumed per hour per gross effective P, | 23·86 | 30·79 | 28·50 | 31·66 | 38·49 |
| 21 | | Pounds of feed water consumed per hour per net effective P., | 26 38 | 34 93 | 33·09 | 40·51 | 58 24 |
| 22 | Temperature in Deg. Fahr. | Of the injection water, | [illegible]6· | 66· | 68· | 64 66 | 64·25 |
| 23 | | Of the water in the weir, | 107· | 118·87 | 111·55 | 99·88 | 101·6 |
| 24 | | Of the feed water, | 87· | 102· | 114· | 112· | 106· |
| 25 | | Per cent. of the amount of feed water that passed into the cylinder from the boilers, in the form of water entrained in the steam, due to incomplete evaporation, | 8·86 | 9 18 | 7·00 | 7·35 | 8·37 |
| 26 | | Total pounds of steam in the cylinder at cut off, calculated from the pressure of the steam in the cylinder at the point of cut-off, | 4153·34 | 3144·612 | 3476·82 | 2180·79 | 1690·848 |
| 27 | | Pounds of steam in the cylinder at cut-off; calculated from the pressure of the steam in the cylinder at the point of cut-off, at the end of one hour, | 2076·67 | 1796·92 | 1738·42 | 1090 395 | 845·424 |
| 28 | | Total pounds of steam in the cylinder at release; calculated from the pressure of the steam in the cylinder, immediately before the opening of exhaust, | 4604·858 | 3590·129 | 3860·15 | 2595·92 | 2103 209 |
| 29 | | Total number of thermal units in the steam, expended by the engine as calculated from the feed water, | 6580861 87 | 6078084 2 | 5673358·6 | 3846859·43 | 2916473·8 |
| 30 | | Total number of thermal units, as per weir, | 5578070·5 | 5286598 9 | 4908042·3 | 3362025·9 | 2586046·9 |
| 31 | | Per cent. of the steam evaporated in the boilers, not accounted for by the indicator, at cut-off, | 35·24 | 47·83 | 36 84 | 41·43 | 41·19 |
| 32 | | Temperature corresponding to the boiler pressure, | 323·657 | 313·134 | 299·815 | 282·954 | 262·451 |
| 33 | | Temperature corresponding to the back pressure, | 160·663 | 164·253 | 164·253 | 162·330 | 160 941 |
| 34 | | Range of temperature worked through, as per card, | 162·994 | 148·881 | 135 562 | 120·624 | 101·510 |
| 35 | | Range of pressure worked through, as per card, | 89·88 | 76·30 | 61·78 | 46 7 | 32·15 |

ion.

22·3

м.
ɩ5, May
м.
²7, May 27.
120

8151
2875·2
1437·6
2 4642

67·925
23·
·2209
·242

26·74
7·96

10·32
3·5
6·82

66 09

37·343
24·68

38·49
58·24

64·25
101·6
106·

8·37

1690·848

845·424

2103 209

916473·8
586046·9

41·19
262·451
160 941
101·510
32·15

*Time.*—Lines 1 to 3 contain the time of commencing and ending experiment and of duration in consecutive minutes. As the contents of the lines in each of the groups of Table 1 have been clearly stated, and the manner of obtaining the results, where there may have existed any seeming obscurity, clearly outlined by formulæ and direct applications, it is not deemed necessary here to repeat the statements regarding each line and group; but those only will be explained that have been added to the groups. The numbers of the lines of Table 2, do not follow those of Table 1; but are similarly worded, so that reference can easily be made by referring to the groups in each of the cases.

*Engine.*—Line 10 contains the fraction of the apparent stroke completed when the steam was cut off; this is the ratio which the length of the stroke up to the point of cutting off the steam is, of the total length of the cylinder.

Line 11 contains the fraction of the (real) stroke completed when the steam was cut off, and is the ratio which the length of stroke to the point of cut-off plus that due to clearance, is of the total length of the cylinder plus that due to clearance.

Line 32 contains the temperatures corresponding to that of the steam in the boilers. It is obtained by interpolating in Porter's tables.

Line 33 contains the temperature corresponding to the back pressure on the piston as taken from the indicator diagrams.

Line 34 contains the range of temperature worked through as per card, and is the difference between the quantities on lines 32 and 33.

Line 35 contains the range of pressure worked through as per card, and is obtained by taking the difference between the heights of the admission line of the indicator card and the back pressure line, both calculated from a common zero multiplied by the scale of the spring used in the trial.

## 25. CALCULATIONS IN DETAIL—RESULTS DISCUSSED AND CLASSIFIED—FINAL EXPRESSIONS AND CURVES REPRESENTING THEM.

The variation of the conditions intended to have been kept constant in this trial have already been alluded to. Though these variations are a trifle greater than those of the first case and as the corrections for condensation with varying ratios of expansion can

not well be applied; the results are taken as put down in Table 2, we thus have, for a

| | |
|---|---|
| Pressure of 80· pounds; | a condensation of 35·24 per cent. |
| 66·85 | 47·83 |
| 52·33 | 36·84 |
| 37·0 | 41·43 |
| 22·3 | 41·19 |

from which we see that the condensation changes slowly with changes of pressure and temperature.

Thus in a variation of pressure of nearly sixty pounds the per cent. of condensation and (excepting one case) varies but six per cent. As already stated, some error must have been made in the observation of the second trial of May 26th, and that the final result will not be taken into account.

Plotting the results of Table 2 on paper, upon which the abscisses represent the per cent. of condensation and the ordinates the pressures in the boilers, we find that the intersections are nearly in line; so that if it were attempted to pass a curve through these four points, it would be very irregular and could not be algebraically expressed.

26. METHOD OF DEDUCING ALGEBRAIC EXPRESSION FOR VARIATION OF CONDENSATION IN CASE II, AS A FUNCTION OF THE BOILER PRESSURE.

The results of the trials of Case II, cannot be applied to the finding of an expression representing the law of condensation for this case, as the values given by the right line of *Plate IV* do not correspond with the calculated results.

Let $(x' \; y')$ and $(x'' \; y'')$ be the two points through which the right line

$$x = my + b$$

is made to pass. The coördinates of the point must satisfy the equation to the line; hence, we have the two equations of condition,

$$x' = my' + b$$
$$x'' = my'' + b$$

Taking the values of $(x' \; y')$ and $(x'' \; y'')$ from *Plate IV*, substituting them in the equations of conditions, and eliminating, we obtain, for the value of the constants $b = 45$ and $m = -0.1266+$.

Substituting these in the ordinary equation to the right line, we have

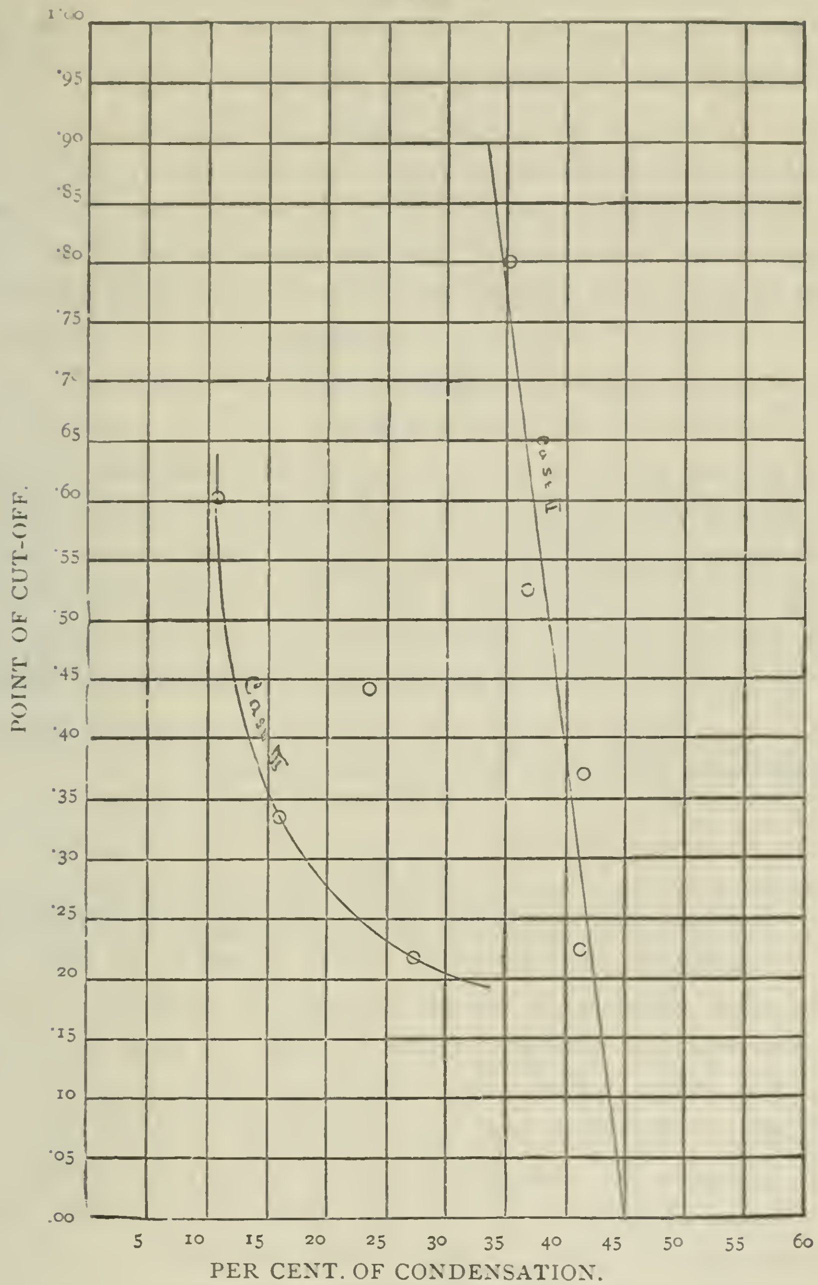
$$x = 45 - 0{\cdot}1266 \, y \qquad E.$$

## Case III.—Non-Condensing.—Variable Boiler Pressure.

*Table No. 3.*—Containing the Data and Results of the Experiments made at Sandy Hook, Conn., to determine the Law of Cylinder Condensation.

| Number of Line. | | | | Variable Steam Pressures of the Boilers. | | | |
|---|---|---|---|---|---|---|---|
| | | | | 60·15 | 44·09 | 33·5 | 21·69 |
| 1 | | Time | Date of commencing experiment, | A. M. 7 30 May 28. | A. M. 11 08, May 28. | P. M. 2·19, May 28. | P. M. 1·50, May 27. |
| 2 | | Time | Date of ending experiment | A. M. 10 30, May 28. | P. M. 1 38 May 28. | P. M. 5·19, May 29. | P. M. 4 50, May 27 |
| 3 | | Time | Duration of experiment in consecutive minutes, | 180 | 150 | 180 | 180 |
| 4 | | Total Quantities | Number of double strokes made by the engine piston, per counter, | 12237 | 10286 | 12153 | 11973 |
| 5 | | Total Quantities | Number of pounds of feed water pumped into boilers, per meter, | 11218 | 8421. | 7332·42 | 554[illegible] 43 |
| 6 | | Total Quantities | Number of pounds of feed water pumped into boilers, per hour, | 3739·33 | 3368 4 | 2444·14 | 184[illegible] 81 |
| 7 | | Engine. | Number of double strokes made per minute by the engine piston, | 67 98 | 68·57 | 67 51 | 66 52 |
| 8 | | Engine. | Fraction of the stroke of piston completed when steam was cut off (apparent) | 3955 | 4 34 | ·384 | 451 |
| 9 | | Engine. | Fraction of the stroke of piston completed when steam was cut off (real) | ·4121 | ·4198 | ·401 | 4[illegible] |
| 10 | Steam Pressures | | In pounds per square inch above atmosphere in boilers, per gauge, | 60 15 | 44 09 | 33·5 | 21·69 |
| 11 | Steam Pressures | In Cylinder per Indicator | In pounds per square inch above zero at cutting off the steam, | 65 36 | 5[illegible]·42 | 4[illegible] 52 | 28 4[illegible] |
| 12 | Steam Pressures | In Cylinder per Indicator | In pounds per square inch above zero at release, | 27 66 | 22·28 | 18 02 | 14 25 |
| 13 | Steam Pressures | In Cylinder per Indicator | In pounds per square inch above zero against the piston during its stroke, | 14 7 | 14 82 | 14 88 | 14 84 |
| 14 | Steam Pressures | In Cylinder per Indicator | Mean gross effective pressure in pounds per square inch on piston during its stroke | 34 87 | 23 85 | 15 84 | [illegible] 04 |
| 15 | Steam Pressures | In Cylinder per Indicator | Pressure in pounds per square inch required to work the engine, | 3 5 | 3 5 | 3 5 | 3 5 |
| 16 | Steam Pressures | In Cylinder per Indicator | Mean net effective pressure in pounds per square inch on piston during its stroke, | 31 [illegible]7 | 20 35 | 12 34 | 4 54 |
| 17 | Steam Pressures | In Cylinder per Indicator | Per cent of which the mean net effective pressure is of the mean gross effective pressure, | 89 96 | 85 32 | 77·90 | 56 45 |
| 18 | Power. | Absolute. | Gross effective horses-power, developed by the engine, | 126 5[illegible] | 87·23 | 57 05 | 28 51[illegible] |
| 19 | Power. | Absolute. | Net horses-power, usefully applied, | 113 80 | 74 4[illegible]4 | 44 442 | 16 09[illegible] |
| 20 | Power. | Economic. | Pounds of feed water consumed per hour per gross effective P. | 29 56 | 38·62 | 42 84 | 64 75 |
| 21 | Power. | Economic. | Pounds of feed water consumed per hour per net effective P., | 32 85 | 45·[illegible]6 | 54 99 | 114 80 |
| 22 | Temperature in Deg. Fahr. | | Of the feed water, | 112 77 | 95·4 | 98 905 | 104 11 |
| 23 | Temperature in Deg. Fahr. | | Of the steam corresponding to the pressure in the boilers, | 307 251 | 291 192 | 278·549 | 261·461 |
| 24 | Temperature in Deg. Fahr. | | Of the steam corresponding to the back pressure on the card, | 212·00 | 212·4[illegible]1 | 212 609 | 212 471 |
| 25 | Temperature in Deg. Fahr. | | Of the range worked through, as per card, | 95·251 | 78·791 | 65 940 | 48·990 |
| 26 | | | Per cent. of the amount of feed water, that passed into the cylinder from the boilers, in the form of water entrained in the steam, due to incomplete evaporation, | 8 15 | 7·44 | 10·23 | 8 7 |
| 27 | | | Pounds of steam in the cylinder at cut off, calculated from the pressure of the steam in the cylinder at cut-off, at the end of one hour, | 3333 69 | 2576 32 | 2055·07 | 1341·83 |
| 28 | | | Pounds of steam in the cylinder at release, calculated from the pressure of the steam in the cylinder immediately before the opening of exhaust, at the end of one hour, | 3439·65 | 2819·72 | 2241·48 | 1848·16 |
| 29 | | | Number of thermal units in the steam expended by the engine, calculated from the feed water consumed, | 12726945·1 | 9558675 1 | 8102018 9 | 6165029.6 |
| 30 | | | Number of thermal units in the steam expended by the engine, calculated from the feed water consumed, at the end of one hour, | 4242315· | 3823470· | 2700672· | 2055003·2 |
| 31 | | | Thermal units per hour, equivalent to the gross effective horse-power, | 324437· | 223719· | 146316. | 73133· |
| 32 | | | Per cent. of the steam evaporated in the boilers not accounted for by the indicator at cut-off, | 10·85 | 23 51 | 15 92 | 27·34 |

PLATE IV.




CONDENSATION WITH VARYING PRESSURE.

This equation representing the law of cylinder condensation for this engine, as a function of the boiler pressure, we will now test; by substituting $y = 80{\cdot}0$, $52{\cdot}33$, $37{\cdot}0$ and $22{\cdot}3$, and compute the values for $x$, we thus find,

$y$ = pressure = 80·0 ; $x$ = cylinder condensation = 34·88 ; error of — ·036
= 52·33 ; = 38·38 ; + 1·54
= 37·0 ; = 40·32 ; — 1·11
= 22·3 ; = 42·27 ; + 1·08

This equation, though it does not absolutely represent the values as found by experiment may be taken to represent the law of condensation, for this engine as a function of the boiler pressure.

27. DISCUSSION OF THE EQUATION.

In equation $E$, if the pressure be zero then $y = o$ and $x = 45$; that is, 45 per cent. of the steam will be condensed if the steam were used under atmospheric pressure and to a cut-off and speed corresponding to that used in the trials. If we let $x = o$ we have,

$$o = 45 - 0{\cdot}1266\, y$$
$$0{\cdot}1266\, y = 45$$
$$y = 355 + .$$

That is at a pressure of 355 pounds to the square inch in the boilers, and at this cut-off and speed there would be no condensation. At 80·0 pounds pressure we have 34·88 per cent. condensation, and at 60·0 pounds 37·4 per cent. Comparing these two latter figures with those obtained in Case I, and corresponding nearly to the same cut-off, pressure and speed, they agree so closely that this equation may safely be taken as representing the law of condensation as a function of the boiler pressure.

## Case III.

The experiments comprising Case III were made without the use of a condenser, and with the boiler pressure as the variable function, the speed and cut-off remaining constant. In other words, the test was similar to that of Case II, with the object of finding the effect which the condenser exerts upon cylinder condensation. The data and logs belonging to this case will be found in Chapter III. On account of the steam demanded by the engine, it was impossible to run the pressure up to that used in the condensing tests, as a greater cut-off was used. The greatest average pressure obtained in this set was that of the first trial, on May 28th, when the fires were at their best, the average pressure being 60·15 pounds; trials were also made at 44·09, 33·5 and 21·69 pounds to the square inch.

The real cut-offs under which the tests were run corresponded to nearly ·41, the apparent ratio of expansion, therefore, being about 2½.

(*See Table No. 3.*)

The quantities are summarized and placed under their respective headings, as in the previous tables. The lines are numbered, and the first twenty-five correspond, with one exception, to those of Case II. It will therefore not be necessary to review these again.

Line 29 contains the thermal units, as calculated from the amount of feed water pumped into the boilers and delivered to the engine. The heat units in a pound of steam and water were taken from Porter's tables. The product of the heat units in one pound of a mixture of steam and water into the whole number of pounds delivered to the engine gives the quantity on line 29.

Line 30 contains the thermal units expended by the engine in one hour, and is found by dividing the quantity on line 27 by the duration of the test in hours.

From Table 3, we see that the per cent. of condensation corresponding to 44·09 pounds pressure is probably too high, as compared with the others. As there are only four trials in this case, and as a curve cannot well be traced through the plotted results, as shown on *Plate IV*, the curve was passed only through three points.

Further calculation and discussion is not deemed necessary, as the curve representing any one of the conic sections could be passed through these three points. It can, however, be seen that the curve has a similar direction to that of Case I, and that the tendency of it is asymptotic, as in the first case.

## CHAPTER VI.

### 28. CALCULATIONS AND LAW OF CASE IV.

Tests 14, 15 and 16 of Case IV were the last trials made, and were for the object of finding the effect of speed or varying time of exposure upon the amount of condensation in the steam engine cylinder, the constant conditions being boiler-pressure and ratio of expansion. From the logs and Table 4, we see that the conditions have been kept about at the same point during the three trials. It is unfortunate that a fourth one was not obtained, but the engine after that time was used to furnish the power for the mill. A fourth point would have definitely settled which direction the curve would have taken. As the three points found are, however, so nearly in line when plotted, we will consider the equation to be that of a straight line, and base the law thereupon accordingly. The revolutions are 62·977, 50·3 and 33·74, corresponding respectively to the 16th, 15th and 14th tests, of which the logs are given in Chapter III. Steam was permitted to follow full stroke and the real cut-off corresponded nearly to the opening of the exhaust and was for the apparent ·9367, ·9604 and ·9803 of the stroke of the engine, and for the real cut-off, ·9384, ·9614 and ·9809.

The boiler pressure was kept as nearly constant as possible, the average pressure being 19·25. The greatest variation being ·32 of a pound from the average, an amount which cannot in any way affect the results of the per cent. of condensation obtained.

### 29. GENERAL METHOD FOR CASE OF VARYING TIME OF EXPOSURE AND SPEED OF ENGINE.

In the annexed table, will be found the observed data and the calculated results of the experiments made for the purpose of determining the law of cylinder condensation as a function of the speed of the engine.

(*See Table No. 4.*)

The experiments are three in number, and the results are arranged in parallel columns under the respective speeds of 62·977, 50·3 and 33·74 revolutions per minute. The engine could not well be run lower than thirty-three revolutions, though had it been possible to supply more steam, a higher speed might have been obtained.

The quantities, for facility of reference, are arranged as far as

### Case IV.—Condensing—Variable Revolutions.

*Table No. 4.*—Containing the Data and Results of the Experiments, made at Sandy Hook, Conn., to determine the Laws of Cylinder Condensation.

| Number of Line. | | | Variable Revolutions. 62·977 | 50·3 | 33 74 |
|---|---|---|---|---|---|
| 1 | Time. | Date of commencing the experiment, | P. M. 3·00, May 29. | A. M. 9 47, May 29. | A. M. 7·57, May 29. |
| 2 | | Date of ending experiment, | P. M. 4 30, May 29. | A. M 11·47, May 29. | A. M. 9·42, May 29. |
| 3 | | Duration of experiment in consecutive minutes, | 90 | 120 | 105 |
| 4 | Total Quantities. | Number of double strokes made by the engine piston, per counter, | 5668 | 6036 | 3543 |
| 5 | | Number of pounds of feed water pumped into boilers, per weir, | 6173·75 | 7331·6 | 4731·82 |
| 6 | | Number of pounds of feed water pumped into boilers, per weir per hour, | 4115·83 | 3665·8 | 2703·897 |
| 7 | | Average height of water over weir, in inches, | 4·1434 | 2·9671 | 2·2505 |
| 8 | Engine. | Number of double strokes made per minute by the engine piston, | 62·977 | 50·3 | 33·74 |
| 9 | | Vacuum in condenser, in inches of mercury, per gauge, | 23·625 | 22·208 | 20· |
| 10 | | Fraction of the stroke of piston completed when the steam was cut off (apparent), | ·9367 | ·9604 | ·9803 |
| 11 | | Fraction of the stroke of piston completed when the steam was cut off (real), | ·9384 | ·9614 | ·9809 |
| 12 | Steam Pressures. In Cylinder per Indicator. | In pounds per square inch above atmosphere in boilers, per gauge, | 19·05 | 19·04 | 19·67 |
| 13 | | In pounds per square inch above zero, at cutting off the steam, | 27·38 | 28·35 | 28·53 |
| 14 | | In pounds per square inch above zero, at release, | 25·71 | 27·91 | 28·53 |
| 15 | | Mean gross effective pressure in pounds per square inch on piston during its stroke, | 21·61 | 22·26 | 22·04 |
| 16 | | Pressure in pounds on the square inch required to work the engine, | 3·5 | 3·5 | 3 5 |
| 17 | | Mean net effective pressure in pounds per square inch on piston during its stroke, | 18·11 | 18·76 | 18 54 |
| 18 | | Per cent. of which the mean net effective pressure is of the mean gross effective pressure, | 83·80 | 84·28 | 84 12 |
| 19 | Power. Absolute. | Gross effective horses-power developed by the engine, | 72·64 | 59·76 | 39·69 |
| 20 | | Net effective horses-power usefully applied, | 60·87 | 50·37 | 33·39 |
| 21 | Power. Economic. | Pounds of feed water consumed per hour, per gross effective horses-power, | 56·66 | 61·34 | 68·12 |
| 22 | | Pounds of feed water consumed per hour, per net effective horses-power, | 67·61 | 72·77 | 80 98 |
| 23 | Temperature in Deg. Fahr. | Of the injection water, | 54·1 | 52·54 | 52·5 |
| 24 | | Of the water in the weir, | 105·3 | 124·5 | 132·42 |
| 25 | | Of the feed water, | 98·2 | 92·5 | 114· |
| 26 | | Per cent. of the amount of feed water that passed into the cylinder from the boilers, in the form of water entrained in the steam, due to incomplete evaporation, | 5·81 | 9·23 | 9·66 |
| 27 | | Total pounds of steam in the cylinder at cut-off, calculated from the pressure of the steam in the cylinder at the point of cut-off, | 4669·058 | 5233·303 | 3146·367 |
| 28 | | Pounds of steam in the cylinder at cut-off calculated from the pressure of the steam in the cylinder at the point of cut-off at the end of one hour, | 3112·7 | 2611·65 | 1797·92 |
| 29 | | Pounds of steam in the cylinder at release, calculated from the pressure of the steam in the cylinder, immediately before the opening of exhaust, | 4669·058 | 5238·002 | 3146·367 |
| 30 | | Total number of thermal units in the steam, expended by the engine, calculated from the feed water consumed, | 6375554·4 | 7195805·61 | 4589394·75 |
| 31 | | Total number of thermal units, as per weir, | 5792506·9 | 6546615·3 | 4192714·5 |
| 32 | | Per cent. of the steam evaporated in the boilers, not accounted for by the indicator at cut-off, | 24·37 | 28 75 | 33·506 |

.)

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92

367

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506

practicable in groups and their lines numbered. The lines, their contents and any new data added have previously received mention, that it is not necessary here to again allude to them separately.

30. CALCULATIONS IN DETAIL—RESULTS DISCUSSED AND CLASSIFIED—FINAL EXPRESSIONS AND CURVES REPRESENTING THEM.

In examining Table 4, it will be seen that the conditions under which the trials were run, were so strictly adhered to, and the results obtained varied so slightly, that an expression from these results determining the per cent. of condensation as a function of the speed, may be taken as strictly representing the losses occurring by condensation in this engine. The greatest variation in the range of pressure for the three tests was three and one-half per cent., a quantity seemingly large, but in reality very small when the low pressure is considered. The greatest variation in the cut-off is not sufficiently large to affect in the slightest degree the per cent. of condensation, as the greatest fluctuation from the lowest to the highest cut-off used amounts to but $\frac{4}{100}$th, which is one-half of one per cent., and but one-fifth of one of the average cut-off.

The per cent. of condensation is given in line 32, from which we have:

| | | | |
|---|---|---|---|
| Revolutions per minute, | 62·977 ; | per cent. of condensation, | 24·37 |
| | 50·3 | | 28·75 |
| | 33·74 | | 33·506 |

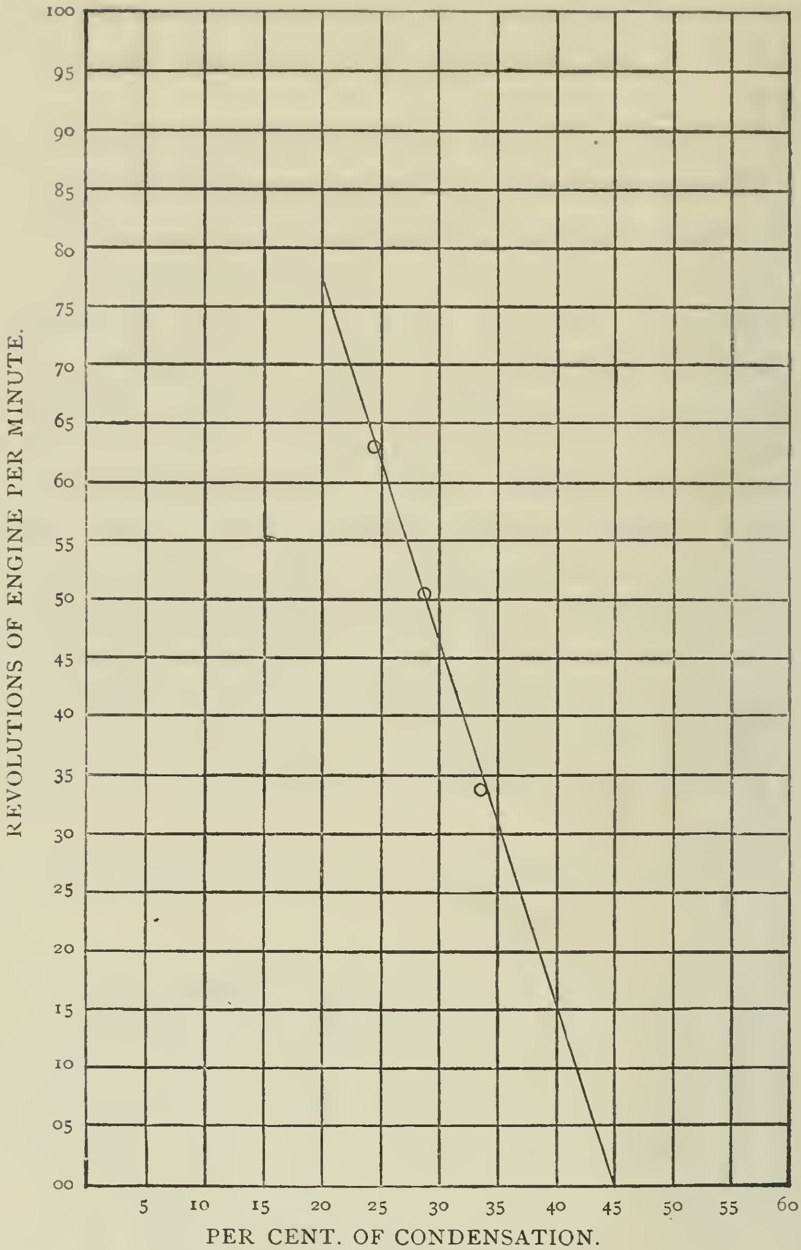
from which we see that the condensation changes inversely as the speed, and in accordance with the opinion of authorities. Plotting the results above obtained, in which the ordinates represent the revolutions made per minute by the engine, and the abscisses the per cent. of cylinder condensation, we find *Plate V* the locus to be a curve corresponding very closely to that of a right line; so that if such a line were passed through any two of them, it would differ but very little from the result as found by experiment.

31. METHOD OF DEDUCING ALGEBRAIC EXPRESSIONS FOR VARIATION OF CONDENSATION IN CASE IV.

Applying the equations to a right line, as in Case II, we find for the value of the constants $m$ and $b$,

$$m = -0{\cdot}33$$
$$b = 45{\cdot}$$

PLATE V.




CONDENSATION WITH ENGINE–SPEED VARIABLE.

and substituting these values of $m$ and $b$ in the equations,

$$x = my + b,$$

we have

$$x = - 45{\cdot}\ 0{\cdot}33\ y \qquad F.$$

We now test equation $F$, by substituting $y = 62{\cdot}977$, $50{\cdot}3$ and $33{\cdot}74$ and computing the values for $x$, we thus find

| | | | | |
|---|---|---|---|---|
| $y$ = Revolutions per min. = | 62·977 ; | $x$ = Cyl. Con. = | 24·22 ; | error — 0·15 |
| | 50·3 | | 28·41 | — 0·34 |
| | 33·74 | | 33·86 | + 0·504 |

This equation then satisfies so closely the results obtained by direct observation, that it may be taken to represent the law of condensation as a function of the varying time of exposure for this engine.

Discussion of the equation. In equation $F$, if the speed be zero, $y = o$, and the condensation, under the conditions of the tests, will be forty-five per cent. of the steam introduced into the cylinder.

If the condensation be zero, $x = o$, and $y = 140$ nearly, or at a speed of 140 revolutions, there would be no condensation.

These latter results are, however, of small consequence, as they result from extending an empirical formula, too far beyond the limits of the experiments, in both directions, upon which it is founded.

ERRATUM.—In Chapter I, § 4, after "incomplete and unsatisfactory," *read:* "for some of the purposes of this investigation."

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SPECTRUM OF OZONE.—Besides the eleven bands observed by Chappuis, E. Schoene has detected one more at wave-length 516, and another, still somewhat doubtful, at about 452. The quantity of ozone in a gas may be determined with the spectroscope, since for a source of light of given intensity, the increase in the amount of ozone is accompanied by the successive appearance of the absorption-bands, the principal band (between 595 and 613) appearing first, the rest following in the order of their intensity. Schoene examined the spectrum of the atmosphere for some time daily before sunrise, and after sunset when the rays passed through a thick layer of air, the remarkable crepuscular phenomena observed throughout the whole of the globe at the end of 1883 having proved highly favorable to these investigations. Although the band of water (599—610, in the liquid, not in the solid state) coincides partly with the main band of ozone, observations made in intense frost, and the sky being entirely bright, leave scarcely any doubt whatever as to the presence of ozone in the atmosphere. The bands are not distinctly seen when the spectroscope is directed towards the sun itself. The so-called rain-band (partly coinciding with the main ozone-band, and extending to line D) also interferes with this kind of observation. This became so intense in spring that it was difficult to detect the presence of ozone in the air. This is the probable reason why in climates more warm and damp than that of Central Russia, the ozone-band could not be observed in the absorption-spectrum of the atmosphere.—*Jour. Chem. Soc., July, 1885.*

# SCIENTIFIC METHOD IN MECHANICAL ENGINEERING.

By COLEMAN SELLERS, Professor of Mechanics, FRANKLIN INSTITUTE.

[*An Introductory Lecture to the Course on Mechanics, delivered before the* FRANKLIN INSTITUTE, *November 6, 1885.*]

A lecture introducing the course on mechanics should in the first place indicate the ground that will be covered by the lecturers who are to follow, and the reason for the selection of the subjects to be treated by them. Owing to the high character of the lectures for this year I find my duty a pleasing one. It is customary to divide the whole lecture course of the FRANKLIN INSTITUTE into three groups, twelve lectures being devoted to Chemistry, and a like number each to Physics and to Mechanics. These lectures, for the greater part, will call attention to matters of importance and not be entirely in the direction of elementary instruction in either branch. Chemistry and Physics are of the utmost importance to all engaged in any industrial art, and in some cases the first plays perhaps the more important part, while Physics, or the study of the laws that govern matter at rest or in motion, is the foundation of applied mechanics. In the broad view taken of the benefit to be derived from the lectures in this hall, the course on applied mechanics, this year is made to serve the purpose of bringing to the notice of the public the results already accomplished in mechanics, through the medium of those who are the most familiar with their accomplishment. We are living in an age of rapid progress, and the discoveries of to-day may be eclipsed by those of to-morrow. America is adding many pages to the history of mechanics, but America will not receive her share of acknowledgment for work done, unless her sons take care to write the history and give to those who have done the work the credit that is their due. The high pressure steam engine was invented in America, here in this very city, yet who is there in England that does not claim the invention for Trevithick, of England. Mr. Coleman Sellers, Jr., who has had his attention directed to the inventions of Oliver Evans, the real inventor of the high pressure steam engine, and who has written on the subject, has been asked to speak of Oliver Evans' inventions that the world may know what an American

did in the early stages of some of the mechanic arts of to-day. At Watertown Arsenal, there is in operation a testing machine, believed to be the most accurate that has ever been constructed, and which is always crowded with work. Its invention involves many new and beautiful mechanical devices. Its inventor, Mr. A. H. Emery, of Stamford, Conn., has been asked to speak about it, and his lecture will be on "Testing Machines as Instruments of Precision."

Mr. Wilfred Lewis, of this city, for a long time engaged in the prosecution of certain investigations in regard to the efficiency of mechanical movements, is therefore in position to give us some very interesting and useful ideas in regard to the loss involved in mechanical powers. His daily work is in the direction of what will be the burden of my lecture to-night. Locomotives have been made in Philadelphia ever since 1830, when Col. Long began his first engine, which was tried on the Newcastle and Frenchtown Railroad in 1831. American locomotives made in Philadelphia are now finding market in all parts of the civilized globe, and so it is very fitting that the story of the growth of the locomotive should be told by some one who has made it a study. Mr. M. N. Forney, lately editor of the *Railroad Gazette*, has consented to come over from New York to lecture on the "Evolution of the Locomotive." Col. William Ludlow, Chief Engineer Water Department of Philadelphia, who is using his best endeavors to give us pure and wholesome water, will lecture on "Water Supplies of Cities."

Iron and coal make a large part of the wealth of the State of Pennsylvania, and the smoke of the thousands of iron furnaces would blacken the air but for the treasure of anthracite that comes from our mines, and the natural gas that is now flowing from the wells in the western part of the State. Mr. John Hartman, whose business it is to construct the machinery used in the process of smelting iron, will deliver one lecture on "The Smelting Furnace," which will interest and instruct in that direction. The flow of solids is a new name coined in quite recent times. Under great pressure, cold metals are made to flow and assume new shapes. Mr. Oberlin Smith, the President of the Ferracute Machine Company, of Bridgeton, N. J., who forces sheet metal into shapes for use, will tell us how sheet metal flows in the drawing process; that is, how it behaves when forced through dies and the like. We are now hoping for a substantial bridge over the Schuylkill River at Market Street, and will be all the

better for some talk on the "Elementary Problems of Bridge Construction," so Mr. James Christie, of the Pencoyd Iron Works, of Philadelphia, has been asked to speak on that subject. The manufacture of worsted goods is carried on to a vast extent in this city, and we scarce realize the extent of that industry in our midst. We are astonished when we are told that more than half of all the carpets made in the world, are woven in Philadelphia, and the carpet industry is but a part of the textile industry of this place. Mr. T. C Search, who takes a most active interest in the school that is now being established in the interest of the textile trades, will give us the technology of worsted manufacture. As an accompaniment to what Col. Ludlow will say as to the water supply of cities, Mr. Rudolph Herring, the eminent hydraulic engineer, will lecture on "Sanitary Plumbing."

In a former lecture of mine, introducing the mechanical course of lectures, I said that in this city "a well-grounded knowledge of the great law or principle of conservation of energy should be taught with the multiplication table. It can be so taught if the teachers themselves are certain that there is in the universe only so much energy, and that we cannot make one particle more than already exists." We are to have one lecture on this subject from Prof. J E. Denton, of the Stevens Institute of Technology, Hoboken, N. J., who will give practical examples of this law of the conservation of energy. Last, but not least, Prof. De Volson Wood, of the same Institute, has promised to lecture, but illness has prevented him from stating his subject; that it will interest and instruct, there can be no doubt. Here, then, in connection with the admirable lectures that are given in the programme under the head of Chemistry and Physics, is presented a course that should crowd this hall.

Outside of what the FRANKLIN INSTITUTE is doing in the way of education through its lectures, its drawing-school. and its more difficult mode of instruction, but even more effective, its exhibitions of novelties in the mechanic arts, this year, is memorable as the one in which manual training has found a beginning in the curriculum of the public schools of the city. It is to be expected that zeal in this new movement, growing out of the interest the students will take in their work and the good fruit it will bear in quickening their perceptive faculties, will encourage the managers of the schools to widen the scope of this kind of tuition.

Manual training will, too, it is hoped, show the need of other lessons in the regular course—lessons bearing on the more extended knowledge of the principles that underlie mechanics. I propose, this evening, saying a few words to you on the part that systematic, scientific method should play in the most ordinary mechanical occupations, and to point out the need of orderly method in the advancement of all the arts. I had occasion, the other day, to watch the operation of a mechanical shoemaker, at work in the Novelties Exhibition. Boots and shoes were being sewed on this machine, the stitches made with brass wire; brass staples were selected, automatically, of the proper length, and were inserted in place. My attention had been critically drawn to this machine in acting as judge in the class to which it belonged; not very far away were books, which, in binding, were sewed with wire staples, and between the two were many devices to enable hand-sewing with wire staples to be done with ease. My mind naturally grouped these objects and processes, and even flew back over many, many years to days of childhood, when I had learned one of my first lessons in mechanics from my father, who held me in his arms, so small was I, as he showed me the then great wonder of fine steel wire bent in a machine into staples and driven through thick leather in rapid succession, to form the fine teeth of the cards used in carding wool and cotton fibre. I was not at, say, five years old, too young to remember the lesson when it was facts that were given me to think over. He took good care to point out that the fine wire forming the staple could be driven through the leather with precision, and without any holes having been pierced for it by more rigid needles, or through holes no larger than the wire forming the staples. The card clothing machines at Cardington were driven by water-power, but this mechanical shoemaker at the Novelties was driven by a steam engine of the highest type. That steam engine had its lesson to teach; a life, too, could span much of the period of transition from the first crude machines that grew out of Oliver Evans' notion of a high-pressure engine to the work of Corliss and others of to-day. It had made but little advance, even as early as I can remember, as compared to the results of to-day, and its slow growth had been after the manner of the survival of the fittest. Its history is cumbered with a vast amount of negative information, by years of mistakes, the result of empirical methods as against the systematic mode of more modern

research. As the steam engine grew towards its present state of perfection, in spite of the many drawbacks, the theory of thermo-dynamics took shape. The practical mechanic, who prides himself on the grand fact that he has drawn all his information, as it were, through the handle of the hammer he has worked with, has a holy horror of all that savors of science, and, what is more, he holds in contempt the scientific engineer. It was one of these practical men who presented a contrivance of his to a railroad company for trial; some of the directors thought it would be well to investigate, and the trial was made. The inventor, after said, that the failure was due to the scientific experts who conducted the trial. He suspected they had put some thermo-dynamics or some other scientific stuff into the boiler, on purpose to prevent his device from operating. Now, thermo-dynamics is the name given to the science that takes into consideration the corelation between heat and work. The desigrers of the great engines of to-day have the advantage of a pretty thorough knowledge of the laws that have been found to govern the conversion of heat into motion and of motion into heat. Could a knowledge of thermo-dynamics have preceded the steam engine, there is no telling how much farther we would have been now in our motive power department of the world's industries.

We are living in an age when the Baconian inductive system of research is relied on; the rapid progress of modern time is due to the results of the inductive system. In old times, the philosophers contrived theories to account for known facts. Lord Bacon was the one who clearly pointed out the need of obtaining many facts and finding the laws that govern matter through and by the study of the facts, but going beyond the range of the facts that we can obtain for the purpose of investigation.

The old philosopher stood on a hill and saw the land spread out before him as a mighty plain, and as he watched the movements of the heavenly bodies, he saw them rise in the East and sink below the horizon in the West. Upon this visible fact, he concluded with the more modern colored preacher in Virginia, that "the sun do move," because he saw it move and so from this visible fact he proceeded to build up a theory of astronomy and hunted for other facts to sustain his theory.

A more modern inductive philosopher, under the same condi-

tions perhaps, notices that objects floating on the surface of the sea sink out of sight at the horizon, and as these bodies are moving, hence infers that the surface of the world is round, and gathering many more facts, he then draws conclusions from his observation that enable him to look farther ahead and foretell, as it were, greater discoveries.

The wonderful progress of modern times is due wholly to the method that has been pursued of grouping facts in proper order, working out laws that govern matter, and proving that the laws are correct by finding no exception to them. An established law is what explains all phenomena bearing on it, and when no known fact offers any contradiction to it. Established laws are many, and the knowledge of these laws make the wisdom of the modern scientific mechanic. There are laws that can be so thoroughly trusted, that we no longer need investigate, and we follow them with confidence, knowing that we cannot change them, if we would do so. Gradually the knowledge of the world has become formulated, and we have in simple form ready for work the accumulated knowledge of all who have preceded us. We have before us, it is true, a vast field of experimental research, but we are in the position to guide our work systematically by the lights we now have. The day for empiricism in mechanics has gone by and I wish to show you this with a few simple illustrations.

I have here a ball, attached to the end of a piece of string, the string seems strong enough to carry the ball; at least, it does not break under the strain. I whirl the ball in a circle, and past experience leads me to infer that if I whirl it rapidly enough the string will break under a strain, due to the centrifugal force incident to the rotation. This fact is so well known to all of you, that it is not needful for me to prove it by trial. We hear of fly-wheels and grindstones breaking when revolved too rapidly. If, for any reason, I should desire to keep up the rotation of the ball at the end of the string with safety, I must know the force exerted on the string during rotation, and I must know the ultimate strength of the string. I have only to know the weight of the ball and its velocity in feet per second during rotation, and calculation will give me the strain on the string more accurately than I could obtain it by experiment. Now, on the other hand, no amount of calculation will tell me if this particular string is strong enough to

bear the strain with safety. To find out the ultimate, or breaking strength of the string, I must load it with an increasing weight until rupture takes place, and the information thus obtained can be used with some degree of certainty with the balance of the twine on the ball from which this was taken, or can be used to predicate the strength of another string of similar size and construction. This homely illustration will convey to your minds what I want to make clear, namely, just where we can rely on calculation, and where experiment must be resorted to continually. Let me now give you an example of the working of the scientific method in actual practice, covering a case involving calculations and experiment. Steam boilers have been made to serve the purpose of death traps from the most culpable neglect of ordinary precautions for safety, coupled with gross ignorance of Nature's laws, until the authorities were obliged to step in and define by laws certain precautions that must be taken for the welfare of the community. Steam boilers are made of sheets of iron or steel bent into shape and joined by rivets. As the strength of the entire structure is limited to the strength of the weakest individual part of the structure, it is of moment that the true value of any particular kind of riveted seam be known by actual experiment. There is no way of making the riveted seam as strong as the body of the metal. It is now usual, to so proportion the number and size of the rivets to the thickness of the plates to be joined, that the metal remaining between the rivet holes, shall about equal the strength of the rivets that unite them. In determining the pressure of steam a boiler already made can be permitted to work under, a calculation is gone into as to the strength of the seam, as measured by the area in section of metal between the rivets, and also measured by the size and number of the rivets, and the strength of the seam is assumed to be the lowest result of the calculation. After this, it may be necessary to know the strength of metal that forms the boiler, and just here is where the lesson of the ball and the string comes into play, and our present illustration is as readily understood. It does not require a very high order of talent to master the calculations that are resorted to, to determine what strain will come on this or that part of the boiler, and we have to rely wholly on calculation, for that information. The boiler must be made much stronger than

its ultimate or breaking strength of the metal to insure its safety in use, and to allow for deterioration. The difference between the ultimate or breaking strength and the strain that it is to be subjected to in practice, is regulated by what is termed the factor of safety. All well-considered specifications for structural metal work, for instance, call for the material to come up to some established standard of ultimate or breaking strength, and the amount of metal to be used in the structure is determined by a factor of safety specified. This factor of safety may be as low as four in some cases of boiler and bridge construction when the known character of the material used warrants the course, or it may be as high as thirty, in the case of matter subjected to shock or blows, as in the case of rapidly-revolving gear wheels. That is to say, it may be considered safe to strain the structure to one-fourth of what would cause it to break, or the case may require that we dare not strain it beyond one-thirtieth of its breaking strength. The question now presents itself, how can every sheet of iron or steel to be used in the construction of a boiler, for instance, be tested when such sheets are usually ordered from the mill of the exact size that is required, and to test a part of such sheet would destroy it for use. This furnishes me with a suitable example of the scientific method carried out whith ease and certainty in every-day practice.

Steam boilers of locomotives are worked at a rather high pressure, say 120 or 130 pounds to the square inch, and the metal now mostly used in their construction, is steel of a low grade as regards hardness, that is, steel of considerable ductility. From the specification for boiler and fire-box steel issued by the General Superintendent of Motive Power of the Pennsylvania Railroad, December 1, 1882, I extract the following :

(1.) A careful examination will be made of every sheet, and none will be received that show mechanical defects.

(2.) A test strip from each sheet, taken lengthwise of the sheet, and without annealing, should have a tensile strength of 55,000 pounds per square inch, and elongation of thirty per cent. in section originally two inches long.

(3.) Sheets will not be accepted if the test shows a tensile strength less than 50,000 pounds, or greater than 65,000 pounds per square inch, nor if the elongation falls below twenty-five per cent.

(4.) Should any sheets develop defects in working, they will be rejected.

(5.) Manufacturers must send one strip for each sheet (this strip must accompany the sheet in every case); both the sheet and strip being properly stamped with the marks designated by this company, and also lettered with white lead to facilitate matching.

Now let me explain this specification to you, as it has been explained to me in the admirable test room of the shops at Altoona:

There are many makers of steel boiler plate in the United States, and without referring by name to any one, I can state that the Pennsylvania Railroad has decided on a set of arbitrary signs to indicate each maker. One is designated by a triangular stamp, one other by a circular stamp that marks a ring of about one inch in diameter, another by a square of like size, and so on. Sheets of steel come from the rolls with a more or less irregular outline and of a size that will permit the tests strip to be cut off from one or the other edge without difficulty. The plate in the rough is, when cold, scribed to the required size of sheet that it is to be sheared to, and on the shear line two marks are made by the prescribed stamp, one mark being made at one blow of the hammer and the other by the same punch or stamp at another blow, and at any convenient distance from the other, but in no case are the two marks made by a twin set of punches or stamps at any fixed distance one from the other. This irregularity of the stamping renders the after matching of the strip, or coupon as it is called, an easy matter, with the sheet from which it has been cut, the shear cut being made directly through the marks. The matching is still further facilitated by numbers or signs in white lead.

After reception by the proper inspectors on the road, the samples, or coupons, are stamped with corresponding numbers after verification, and the test piece goes into the shop to be dressed to the proper width for the test, and the sample is then broken in a testing machine, and, in a book kept for that purpose, entry is made of every particular connected with the test, and the sheet received or rejected on this record. Suppose, however, that a sample shows a higher tensile strength than the maximum allowed, namely, 65,000 pounds per square inch, and that such specimen has an elongation or ductility as great as can be desired

it may be well asked why it should be rejected. In the book of record, I have seen some such cases, and reference is there made to the book of the chemist, into whose hands such sample is sure to go. His chemical test had in all cases, up to the time I saw the book, indicated too much carbon in the steel, and a simple physical test of heating and plunging the hot steel into cold water has shown it to be capable of being hardened. It is not deemed wise to employ any metal that has hardening qualities in the construction of steam boilers. After many such trials, the officers of the road have come to consider the tensile and ductility test as final, and as expressive of the qualities wanted. Thus, you see every sheet in every boiler has its physical quality when new recorded, and its marks enable its after history to be noted. No sheet of steel can meet with mishap afterwards, without having the report of the mishap recorded on the page that marked its acceptance, and its life or durability also noted. Such, in brief, is the account of the admirable scientific investigation into the quality of the material used in boilers, as reduced to practice, and so persistently pursued by this one company as to be now no longer a subject of comment. This method of test, however, is the outgrowth of systems that preceded it. Practice and theory must agree. The scientific engineer can lay claim to the title only when he is abundantly fortified by sound experience, and has learned to view all things evenly.

In the specification of the Pennsylvania Railroad, as already cited, stress is laid on the percentage of stretch before rupture takes place in the required test. The date of the printed specification I have referred to, is 1882. On January 8, 1881, I had a letter from the General Superintendent of Motive Power, in which he describes other tests which had been used for a long time. These were bending tests:

(1.) Bending cold.—A strip from each sheet must stand being bent over double, and being hammered down flat upon itself without fracture.

(2.) Bending after being heated and dipped.—A strip from each sheet must stand being bent over double, and being hammered down flat upon itself, after having been heated to a flanging heat and dipped into cold water, without sign of fracture.

He informed me that the bending tests had been insisted on for

several years, but that the certainty of the ductility test had caused them to make it the final mode of determining the quality of the steel submitted to them. In order to make the bending as uniform as possible, they adopted the plan of holding the strip to be bent between rigid jaws and striking the projecting end with a ten-pound sledge until it is deflected about 135°, when it was removed from the jaws and held with tongs while it was hammered down flat on an anvil. The bending after heating and dipping was added to protect them against acceptance of hard sheets, by reason of the test strips being annealed, accidently or otherwise by the manufacturers. He said that for some time past they had been testing tensilly, to obtain ultimate strength and ductility, a piece from the strip sent with each sheet, and had established a tensile test, which supplanted the bending test, but covered the same ground that it did. This was done on account of the greater regularity and uniformity of the results in tensile test, and because by it they obtain figures to show the exact quality of the steel; so that even in 1881 they were working under the specification I have already mentioned, as furnished me in 1882. Time is an important element in tests, particularly so in bending tests. An expert giving testimony in a trial in which the reliability of the steam engine indicator was in question, said, "I believe in the result of the use of the indicator when I know who works the instrument." The bending test is good, when you see it done in a proper manner, or know who does the bending.

Hurry the bending of good metal and it may break. Proceed with the bending of poor metal with caution, let it rest a bit between each blow, and a skilful man can bend a strip of brittle steel, so that the specimen will deceive the most expert. It is a very curious property of wrought iron and steel, that after being strained above the limit of elasticity and near to the point of fracture, rest will restore its strength. The story is told of some tests being made on beams for structural work before some officers of the Government. One maker strained a beam up to a point near to the breaking point and then invited the Board to test some champagne, saying that he was willing to let the beam remain, under its heavy load until after lunch. When the test was resumed, a strength was shown that could not have been reached had the rupture been hurried to completion and the metal had been allowed no time to accommodate itself to the strained condition.

Let me now go back to the consideration of material used in boilers. During the latter part of Mayor Stokley's administration, say about 1880, he, at the instance of the City Inspector of Steam Engines and Stationary Boilers, and of the officers of an insurance company for inspection and insurance of steam boilers, appointed a commission to devise some fixed rules, whereby uniformity of rating could be insured as to the pressure at which boilers may be worked. I had the honor of serving on that commission, and am thus enabled to tell you that we found a set of rules in force which gave to all boilers of the same diameter and the same thickness of metal the same pressure per square inch, regardless of the quality of the metal employed in construction and of the nature of the riveted seams. Fortunately, however, our City Inspectors of Steam Boilers were practical boiler-makers and were familiar with the requirements and could refuse to pass boilers manifestly unfit for use, for men long familiar with work of this kind come to learn what is right by experience and good common-sense. The ordinances passed by Councils, at the suggestion of the commission, made it imperative that all the conditions that exist in each boiler as to nature of seams, thickness and quality of the metal used, should be considered, and the boilers rated accordingly, giving the greater latitude to good workmanship and good quality of material combined with judicious proportioning of the parts. At the time to which I allude, but a few years ago, the United States laws in regard to the testing of boilers used in the marine service, called only for a knowledge of the tensile strength, and no notice was taken of the softness or ductility of the metal combined with great strength. I know a case in which a sheet had to be selected of higher tensile strength than could be obtained at the time, coupled with much ductility, to repair a boiler so that it would pass the Inspectors under United States laws. A lower ultimate tensile strength with high ductility would have made a safer job of the repair. We have come to the time now, when to hold our place in the world in competition with others, we should waste as little of our energies as possible in cutting and trying in any hap-hazard way and endeavor to avail ourselves of the acquired knowledge of the world generally, and make scientific application of the knowledge in our daily work.

We find it to our advantage to utilize the talent that comes

from the technical schools, only guiding and holding in check the schoolmen until they have learned the lesson of the workshop practice. You must bear in mind that it has been asserted that the *Puritan*, the *Genesta* and the *Pilgrim* were all designed by men who had a theoretical knowledge of boat building, and were not practical builders. The talent shown by the theorist who did save the cup for America in an international contest, might be utilized to advantage in the workshops of the practical boat-builder. On the other hand, the record of failures and mistakes for the want of practical experience, or sufficiently extended knowledge in the endeavors of newly-fledged scientific experts, are many and lamentable, as all know who are obliged to utilize their talents. Scientific men, too, have been charged, often wrongfully, with retarding progress. Dr. Lardner is accused of having stated, in his early lectures delivered in America, that the ocean could not be successfully navigated by steam, mainly on account of the large quantity of coal required, as compared with the carrying capacity of the vessel. It was in 1840 that he lectured here, and he remained in America until 1849. The *Sirius* and the *Great Western* steamships arrived in New York on St. George's day, April 23, 1838. Dr. Lardner's comments were made in England, at Bristol, August 25, 1837, before the Mechanical Section of the British Association. His opinion was asked, and was published in the *Times*, August 27, 1837. He never expressed a doubt as to the practicability as has been stated. The substance of what he then said was that the marine engine, with its then state of efficiency, was not able to cross the Atlantic from England to New York profitably without the patronage of Government. The engines of his day burned eight pounds or more of coal for every hourly horse-power developed, while we can do the same work with two pounds of coal per horse-power and we desire Government subsidy to keep our ships afloat.* Since the time that the *Great Western* steamed into New York harbor, what changes have been made in steam engines and in marine architecture. When in Scotland last year, I visited some of the noted ship-yards on the Clyde. In the yard of the Dennys, at Dunbarton, I was present at the trial of a model in the testing tank to determine the wave-line on the side of the ship. Certain side-wheel steamers were to

* See New York *Times*, January 8, 1881, letter of W. W. Evans.

be built, and it was advisable that the wave-line on the side of the ship, incident to the motion of the vessel, should be so fixed as to have the crest of a wave rise with certainty just where the paddle-wheel struck the water, and not compel the blade to reach down in the valley of the water for its hold in driving the ship forward. Theory had given a shape to produce this wave-line, and a model ship, about eight feet long, cast in paraffine, and worked up to the required lines on an expanse profiling or sculpturing machine was being tested and record made of all the conditions that could be noted by trained experts. In the same building, there were employed, I should think, at least twenty men and women, doing the clerical work of the calculations involved in scientific ship-building.

In London, last year, I was present in the lecture room of the Royal Institution, on Albemarle Street, in the room made celebrated by the exposition of the discoveries of Thomas Young, of Humphry Davy, of Michael Faraday, while each in turn presided over that Institution, and gave to the world, in that room, the result of their close scrutiny into the working of the laws that govern matter. The lecturer of the evening was treating of the motion of fluids, and one of his experiments was so striking that I venture to repeat it now, as it shows how much deeper we must go than the surface of what we see in search for exact truth. He produced a cubical block of wood, such as I now hold in my hand, suspended by a string attached to the centre of one of its faces. See, the block hangs like any other piece of inert matter, with its centre of gravity in line with the axis of the string. We see nothing unusual in the behavior of the block. If I try to make it hang in any other position, the force that placed in position being removed, it falls back to its normal position. If I attempt to make the block stand on one of its edges, it falls over, and we know, after a few trials, that such position is one of unstable equilibrium, and not to be relied on as permanent. I have here, however, a block, also of wood, of the same size and shape as the first one; it, too, is attached to a string; to all appearance, it is a similar block. I hold it in such a position that the string is dependent from one of the vertical faces of the block, and not from the upper one. I hold the string and release the block, and it does not fall from this constrained position, but seems to hang to one side of the

string, in what, to our senses, seems an abnormal position. I stand it on one edge, and it does not fall as did the first block. I might place it in other positions, and the effect would be as striking. Now, what makes one bit of wood act as we are accustomed to see matter act, and the other to act so differently? I will tell you: The first block was what it seemed to be, the second has motion inside of it, and that motion, under certain well-known laws, controlled the position of the block. See, I open the second block, which is hollow, and in the box is a brass top which has been and is yet spinning. The forces concerned in the rotation of the top were powerful enough to control the light form that simulated the block of wood.* The learned lecturer in London used this simple experiment to show what motion will do, and it was one of many experiments in the direction of showing the difficulties that attended the study of the motion of fluids, when motion within the fluid, not visible to the human eye, was exerting a controlling influence, and leading the mind of the observer away from the true facts of the case. I venture to show you this as illustrating the care that must be observed in seeking for truth. It requires a trained mind to follow the most direct road in any complicated investigation into the laws that govern matter, and the same training is needed by every mechanic in the orderly and systematic carrying out of his designs.

I have spoken of the inductive system of investigating the laws of the universe as practised now. Modern scientific advancement is measured by our knowledge of the laws that govern matter, and its progress is in proportion to the abandonment of empirical methods. All knowledge is based on the observation of facts, if we attempt to draw conclusions from too few facts, we may not be wrong in our conclusions when we have to deal with cases involving the same facts, but we may err greatly when our formulated method is carried in practice far beyond the experiments upon which it was based in the first case. I will mention a noticeable example: We are probably indebted to no one more than Morin

* The apparatus used consisted of two cubical blocks, each 6″ x 6″ x 6″; one solid, the other formed of wood $\frac{3}{16}$″ thick, and in this box was a well-made gyroscope in a metal ring, loaned for the occasion by Messrs. Queen & Co., of this city. The attachment of the suspending cord was at the centre of the face of the block, close to one end of the axle of the gyroscope.

for his experiments on friction. No one has been able to controvert what he discovered in regard to the laws of friction, but cases occur in which there seems to be manifest disagreement with his laws, and these cases are always outside of the scope of his series of experiments. In other words, he did not carry his experiments far enough in the direction of velocity and in the direction of pressure, nor do we yet know all the conditions that obtain in the friction of different substances as we approach their destructive limit in use. As we extend our knowledge by still further experiments, we do not find any flaw in his expressed laws, so far as his light went, but we introduce other factors in the equation, factors that were of no moment in the experiments he tried, but which become the prime factors in the more severe requirements of application far beyond his in both directions. We are as yet, with all our information, but on the threshold of knowledge, but we are growing to be sure of one thing, that we have passed the time of empiricism, and to advance profitably we must pursue systematic rules of progress. In the competition of the world, we cannot afford to make mistakes; while to avoid mistakes, we must decide just what we want to do—the character of the material we have to use as well as the forces involved in the operation to be performed. We are to have a new bridge over the Schuylkill at Market Street some time. We are wise enough to know that it will not do to have that structure built by rule of thumb, trusting to rebuild it in a better manner later. It is doing things wrong once, twice and often many times before we stumble on what will barely serve our purpose, that is costing so much money and giving so little satisfaction and retarding progress. We cannot walk a square on any of our cobble-paved streets which should serve the purpose of facilitating the traffic over the road-bed, but we wonder at the want of knowledge shown by those who regulate our municipal matters and have permitted, and still permit, such structures to remain at a constant cost in detriment to the property hauled over them and the discomfort of ourselves. Street railways in many cases have their tracks perched on the centre of a narrow street with so much curve or camber to the pavement that the rail-bed is as high or higher than the curb-stones on either side, and the slanting pavement on either side of the track is on such an incline and so roughly paved with huge round stones, as to set at

defiance all the laws of mechanics, that dictate a road of the least resistance as the most economical, both in wear and tear to the road itself, but to the conveyances that pass over it. The locomotive proposed by Oliver Evans in the beginning of this century was to have run on the country roads, but he, with his limited knowledge, even hinted at special roads made to offer less resistance. Our streets are paved to make the most resistance. The locomotive was useless until it found a road adapted to its purpose. The success of the locomotive depended on the condition of the road it travelled on. Great results followed in practice when a scientifically-constructed and well-laid road was ready for the locomotive. Let us have smooth well laid streets, too.

Cable railroads have been in use in many cities for some years, their construction was experimental, and their present economy is problematical. I am not prepared to say just how scientifically they have been constructed in Chicago and the Far West, but here in our own city we are seeing a gigantic constructive experiment tried on the cut-and-try principle. Metallic conduits for the traction cable are put into place over miles of roads, the conduits being so formed as to have little or no power of resistance against the crush of the frozen ground, and even so made, as to present a shape most favorable to permitting the pavement to wedge the grip-slot shut. Wheels are put in to guide the ropes seemingly without any regard to strains that might have been known beforehand; or, if not known, should have been found out by careful experiment, and the citizens, who should be using the streets to their best profit and convenience, are kept off them by a constant succession of changes, involving tearing up, altering, replacing to the discomfort of our fellow-citizens, and to the loss of the company owning the road. The public are less interested if this cut-and-try system is taking place in the private workshops, and the public cares very little about the stages of progress through which any finished product has passed in reaching the stage of use to the consumer. The public are warranted, however, in objecting to unsystematic and ill-advised engineering enterprises being conducted to their detriment and delay. There will be no end, however, to just such empirical engineering. The desire to save in the first cost, without considering the after result of such false economy, will be the rule perhaps for a longer time in the

future than any one here is interested in, but it is the outgrowth of much evil in the methods of our schools. One of the first objects of education is, I think, to quicken the perception to teach the habit of observing phenomena clearly and quickly, to instil the desire to trace effects to their causes and to cultivate close and just reflection. The elements of geometry, physics and mechanics should have the preference over many of the traditional studies of the primary and the grammar schools, and what is more, the early introduction of such studies, presented to a child's mind in a practical form, as they can be, will prepare his mind for the more extended study of the higher branches of the same subjects in later years. As it is, the alphabet of science is not taught until the student is ready to read the subject in later life, when he should have grown up with a feeling that he always was in a measure familiar with the facts of the science.

General Francis A. Walker, President of the Massachusetts Institute of Technology, in a paper read before the American Social Science Association, September 9, 1884, said, in speaking on this subject: "Do you ask me how much of the elements of physics and mechanics should be given to a child of tender years? I answer, just as much as he will take, be the same more or less. And it is always safe to offer him more than he will take. It can't do him any harm. Cramming him with hard and lumpy facts, from so-called geographies or histories, may produce mental indigestion or colic; but an idea, an apprehended principle, never yet hurt a human being, and never will to the last syllable of recorded time. For myself, I would not stop teaching a child the doctrine of the persistance of force through all transmutations. Doubtless he would at first fail to apprehend it fully; yet he would gather something from it familiar, picturesque enunciation; and as the proposition became familiar to his ear, and as illustrations of the equivalency of motion, heat, light and sound were multiplied and repeated to him, I should hope that he would grow into an apprehension and appreciation of this grand all-embracing law."

He also said that a child often of twelve years is capable of understanding the principle of the lever just as well, or as perfectly, as did Archimedes of old Syracuse, and that if the conception is once implanted in the mind, it will become germinal and will, without watering and tending, bear fruit perennially through his life.

With a higher education in the direction just briefly indicated, the people will more generally come to understand the need of avoiding all empirical practice in the exact sciences and learn the truth that all mechanical processes, all constructive work, in fact all that goes to make up the sum and substance of our surroundings, are governed by exact laws which, if not observed, bring their own punishment for neglect.

## DELANY'S SYSTEM OF FAC-SIMILE TELEGRAPHY*.

By Prof. Edwin J. Houston.

Fac-simile telegraphy embraces the methods by which chirography, outline sketches, maps, hieroglyphics, etc., produced at one end of a telegraphic line, are automatically reproduced at the other end. Such a system embraces a transmitting instrument at one end of a line and a receiving instrument at the other end. These instruments, though varied in form, consist for the greater part of similar surfaces maintained in approximately synchronous motion. The message is written or drawn on one of these surfaces, and is automatically reproduced on the surface at the other end of the line.

Numerous and various devices have been invented for the transmission and reproduction of fac-simile despatches. The principal of these may, however, be arranged under two heads. In one of these classes a pen or stylus, moved by the hand through a magnetic field, sends thereby a series of electrical impulses over the line that produces corresponding movements in a similar pen at the other end of the line. In such apparatus the handwriting or outlines are reproduced directly on the paper or other material that is placed on the surface of the receiving instrument.

In the other class, which embraces the greatest number of apparatus, the transmitting and receiving devices are of the same construction and consist of similar metallic surfaces, such for example as two cylinders maintained in approximately synchronous motion, and each provided with a pen or stylus that

* A paper read before the American Institute of Electrical Engineers, May 20, 1885. For the use of the cuts used in this article we are indebted to the *Electrician and Electrical Engineer*, New York.—(*Com. on Publ.*)

is caused to move over the surface. The pen or stylus is connected to the line so that the current passes from the transmitting instrument over the line and into the receiving instrument. The message to be sent is written on the surface of the transmitting cylinder, in any non-electrical conducting ink, and the surface of the receiving instrument is covered with ordinary Bain paper. When now the instruments are simultaneously set into motion, as long as the stylus or pen is in contact with the metallic surface of the transmitting instrument, it causes a continuous blue line to be traced on the Bain paper at the receiving end. When, however, the stylus or pen is moved over the surface of the non-conducting ink, the circuit is interrupted and the corresponding points on the surface of the receiving cylinder are left unchanged. The design traced on the transmitting instrument is thus reproduced on the receiving instrument in white on a blue ground.

Bain was the pioneer in fac-simile transmission. His devices, which were produced as early as 1843, belong to the second class of apparatus. To the same class belong the inventions of Bakewell in 1850, of Hunter in 1852, of Caselli in 1858, and of Bonelli. The devices of Lenoirs, of Sawyer, of Edison, of others may also be included in the same class.

The apparatus of Jones, produced 1855, and of Myers, belonged to the first class.

Thurrell, Müller and Chidly, in 1856, produced, jointly, an apparatus for fac-simile transmission, in which a magnetized point or roller was moved to-and-fro over the surface of the transmitting apparatus. While the magnetizing current continued to flow, a similar point traced a continuous line on the receiving surface, but whenever a break occurred, as, for example, by the non-conducting ink, the point was drawn away by a spring. The successive makes and breaks so obtained produced on the receiving cylinder the design traced on the transmitter.

Hitherto, the various systems of fac-simile transmission have failed in their successful commercial applications, either because of their unreliability, or from their great expense. When a single stylus or pencil was employed, as in the system of Bakewell, Caselli and others, the method was slow in operation and unreliable in its results. Bonelli's introduction of a multiple comb or stylus, in which a series of styluses or fingers at each station were

employed, connected between the two stations by a cable containing as many single conducting wires as there were fingers in the compound stylus at each station, increased the speed of transmission.

Bonelli's system, as will be readily understood, was a great improvement on the systems known at the time of its invention. Two difficulties, however, existed which have prevented its extensive use. These were,

(1.) The great expense of construction when the cable connected two distant stations, and,

(2.) The unreliability in the results attained, owing to the interferences in the strength of the momentary impulses sent through the separate wires of the cable, by induction in or by neighboring wires.

Mr. Delany has happily applied his system of synchronous-multiplex telegraphy to fac-simile transmission and has attained results that appear to render the actual commercial application of fac-simile telegraphy practicable. His system, briefly, consists in dividing a single telegraph wire, connected at each of its ends to a multiple comb, or series of styluses, into as many separate and practically distinct lines as the separate and distinct styluses at either end. The division of the single connecting wire into a number of separate lines is effected by his system of synchronous multiplex telegraphy, now so generally understood.

The means, whereby this application is made, will be better understood by an examination of *Fig. 1*, for which, in common with all the figures used in this paper, the author is indebted to the United States Letters Patent, granted to Mr. Delany for fac-simile transmission. In *Fig. 1*, is shown the transmitting and receiving apparatus connected with the synchronous distributor. In this figure, *X*, and *Y*, are the two stations. *A*, is the rotating disc, and *a*, its trailing finger or circuit completer, mounted on the axis of the disc *A*. *B*, is the circular table of insulated contacts. Eighty-four of these contacts are provided in this case, divided into six series of fourteen each.

The thirteenth and fourteenth contacts in each of these series is not shown as connected in the figure, these contacts being reserved for the synchronous correction of the apparatus, in accordance with the Delany synchronous-multiplex system.

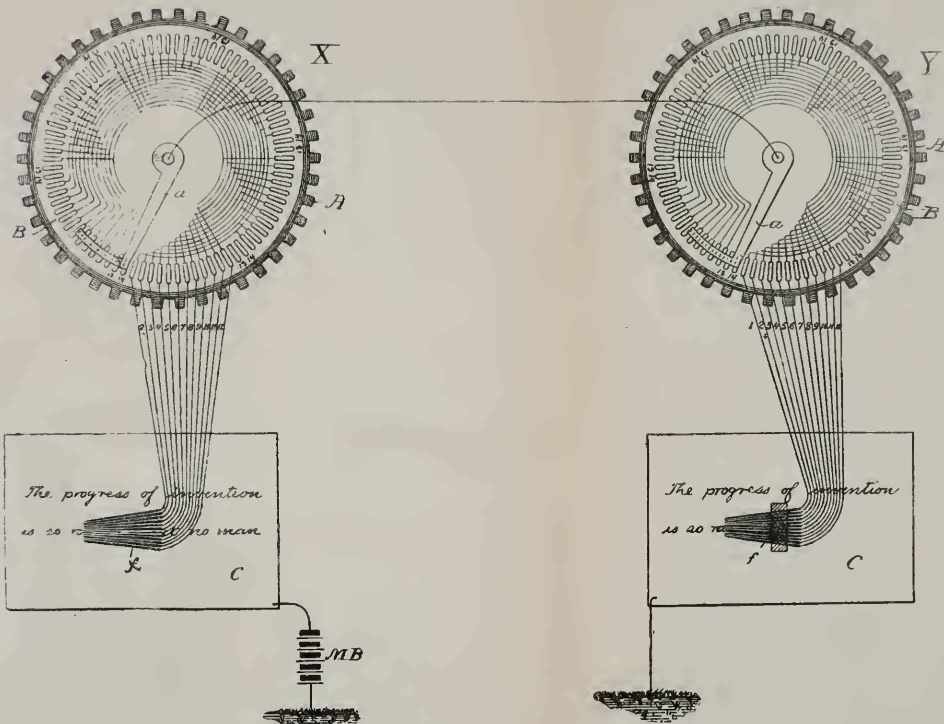



FIG. 1. Delany's Fac-Simile Apparatus.

Supposing the contacts in each of the six groups to be numbered from 1, to 14, consecutively, the number-one contacts in each of the six groups are connected together and to a line marked 1, at station *Y*, and the corresponding contacts similarly connected at station *X*, to a line marked *X*. The number-two contacts at each station are similarly connected to one another and to a line marked 2, and so with the other contacts, the thirteenth and fourteenth in each of the groups being reserved for the sychronizing of the line as already explained.

Each of the lines 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, so provided, is connected to an insulated finger or stylus *f*, that forms part of a comb that moves over the surface of the transmitting and receiving instruments *C*, *C*.

When, now, the synchronously moving fingers *a*, *a*, move over the contacts, they simultaneously rest on similar or corresponding contacts at each end of the line, thus completing the circuit from the insulated finger *f*, in said circuit 3, at station *X*, with the insulated finger *f*, in circuit 3, at station *Y*.

If the trailing fingers are rotated at a speed of say three times per second, the circuit will be completed over each of the twelve lines so provided between the two stations, eighteen times a second. At this rate a high speed of transmission is attainable. The insulated fingers are arranged, as shown in the figure, on a comb in close proximity to one another, but separated by some good insulating material. The plates *C*, *C*, on which these fingers rest, are maintained in approximately synchronous motion by clockwork or other suitable mechanism.

The battery *M B*, at one of the stations as *X*, has one of its poles connected to ground, and the other to the metallic plate *C*. Let us suppose now that *X*, is the transmitting station and *Y*, the receiving station, and that the message to be transmitted is written on the surface of *C*, at *X*, in some electrical non-conducting ink, while the surface of the receiving apparatus at *C*, is covered with a sheet of Bain or chemically prepared paper.

When now the ends of the fingers *f*, at *X*, are in direct contact with the metallic plate, the circuit of the battery *M B*, will be independently completed through each of the twelve lines, eighteen times per second through the fingers at *Y*, to the ground, and will thus produce the well-known blue marks or lines on the paper at

that station. When, however, the circuit is broken by the trailing finger at *X*, coming in contact with the insulating ink, the otherwise continuous line marked on the paper at *Y*, will appear broken, no discoloration appearing at such point. Whatever therefore is traced on the transmitting surface is automatically reproduced on

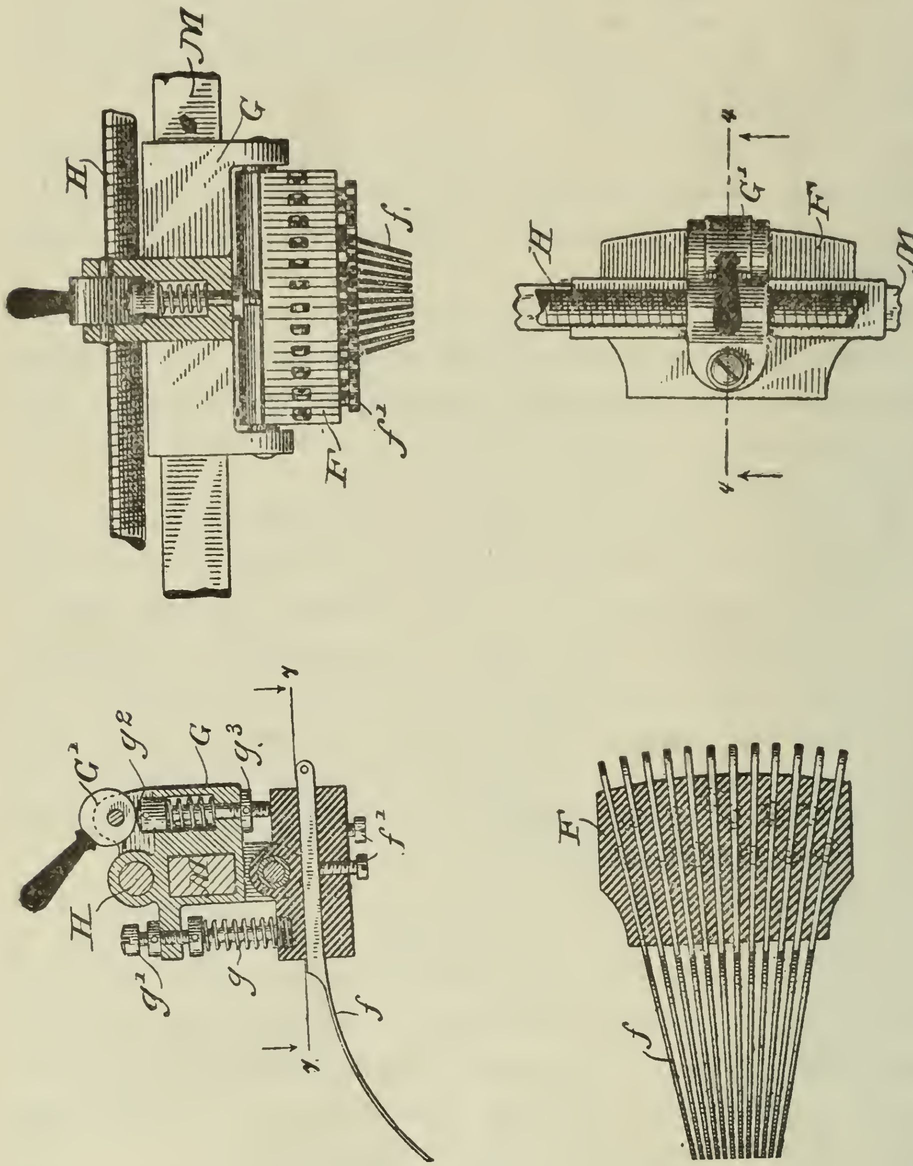


FIG. 2. Details of Multiplex Stylus or Comb.

the receiving surface in white lines on a nearly continuous blue ground.

Although any series of points in a straight line in the design traced on the transmitting surface, that were simultaneously touched by all the twelve separate and independent fingers, would

not be actually reproduced on the surface of the receiving apparatus as a rigorously straight line, since the electrical impulses would not be simultaneously sent over all the lines but over each in succession, yet in actual practice the completion of the circuits

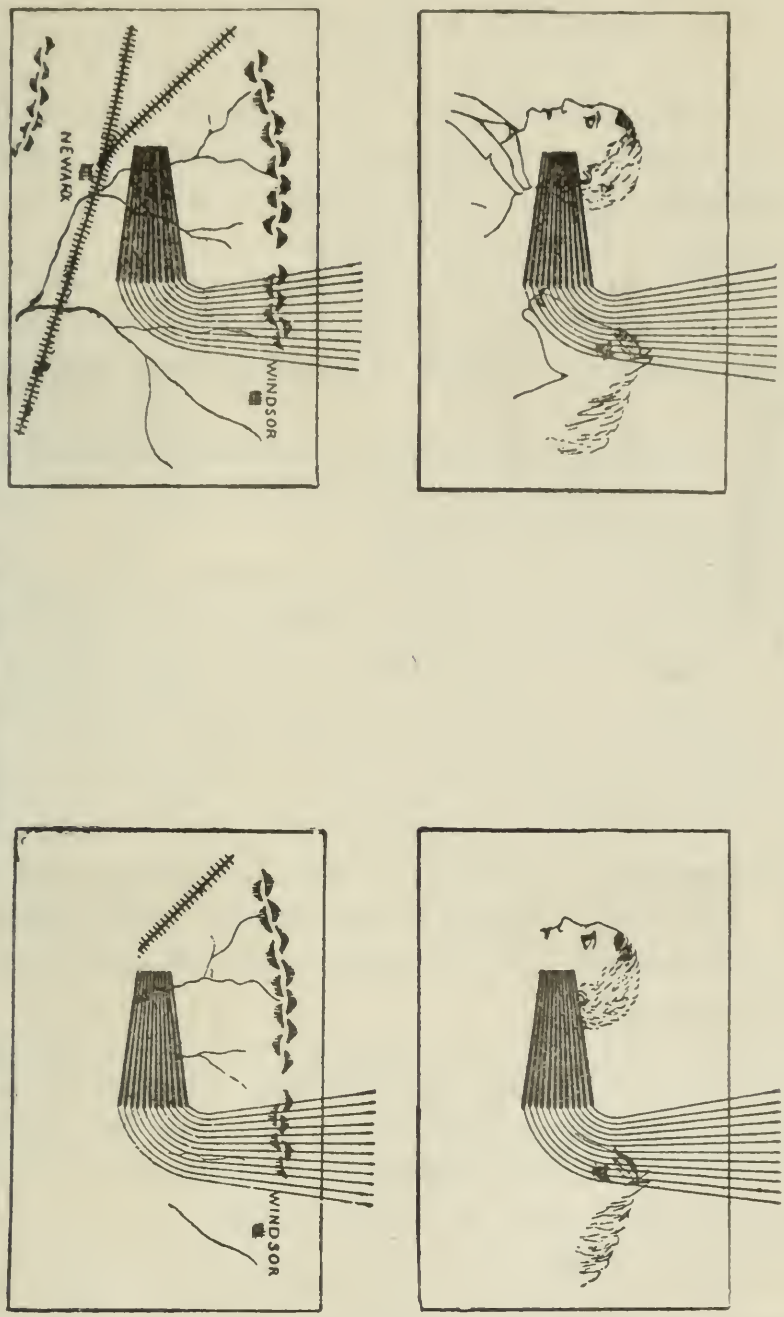



FIG. 3. Fac-simile Transmission.

in each of the separate lines occurs at such frequent intervals, that the deviation from the straight line in the case supposed is not discernible, and the effect is the same, as if the corresponding fingers at the two styluses were actually connected by separate and independent main lines.

In *Fig. 2*, are shown some of the details of the multiplex stylus or comb with its trailing fingers.

The separate fingers $f$, are mounted in the insulating block $F$, by being pressed through slots or apertures in said block. Set screws $f^1$, are provided for holding the fingers in position and for permitting their adjustment. The block $F$, pivoted at $G$, moves over the screw threaded shaft $H$. A spring $g$, adjustable by $g^1$, keeps the styluses pressed against the surface of the metallic plate $C$. The depression of the trailing finger is limited by the bolt $g^2$, and its collar $g^3$, in the manner shown.

The cam $G^1$, is provided for pressing down the bolt $g^2$, so that when $C$, has reached the end of its motion, the fingers may be held away from the plate $C$, while it is being drawn back again into position.

In *Fig. 3*, is shown the fac-simile transmission of a drawing, and of a map. The transmitting station is on the left of the drawing, the receiving station on the right.

Any method may be adopted for the motion of the movements of the transmitting and receiving surfaces $C$, $C$. Mr. Delany has shown a number of such devices in his United States Letters Patent. In *Figs. 4*, *5*, and *6*, are shown the details of a device suitable for obtaining a reciprocating motion of the plates $C$, $C$. The frame of the instrument is shown at $I$. The plate $C$, is driven by a rack $C^4$, actuated by any ordinary clock-work $K$. A screw shaft $H$, has its bearings on the lugs or vertical standards $I$, situated as shown. The comb is carried by the frame $G$, which moves laterally on the string-bar $M$, connecting the standards $L$, $L$, as the shaft $H$, is rotated

A much neater and more practical method for obtaining the motion of the transmitting and receiving apparatus is shown in connection with *Figs. 7*, and *8*. In this form the reciprocating motion of the preceding apparatus is replaced by a continuous rotary motion of the plate as will be explained.

In this form of apparatus a rotary cylinder $C$, replaces the plate $C$, $C$. "The gear wheel $N$, driven from the clock-train, gears with a wheel $N^1$, which is loose on the screw-shaft $H$. The wheel $N^1$, is normally locked on the shaft by a spring catch, $O$, which is pivoted in a collar on the end of a shaft and engages with the teeth of a gear-wheel, $N^2$, fast on the shaft."

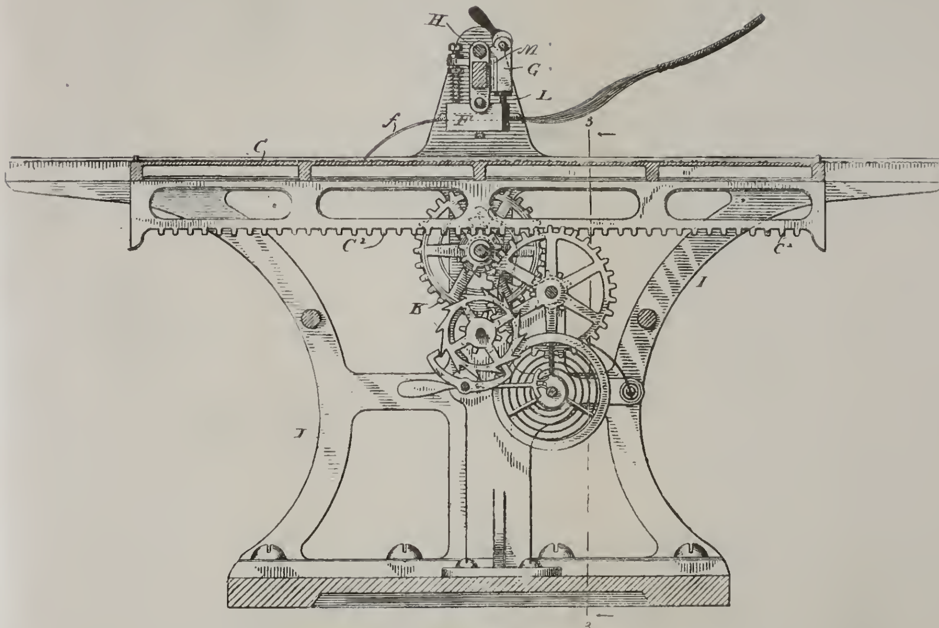



FIG. 5. Device for Reciprocating Motion of Transmitting and Receiving Apparatus.

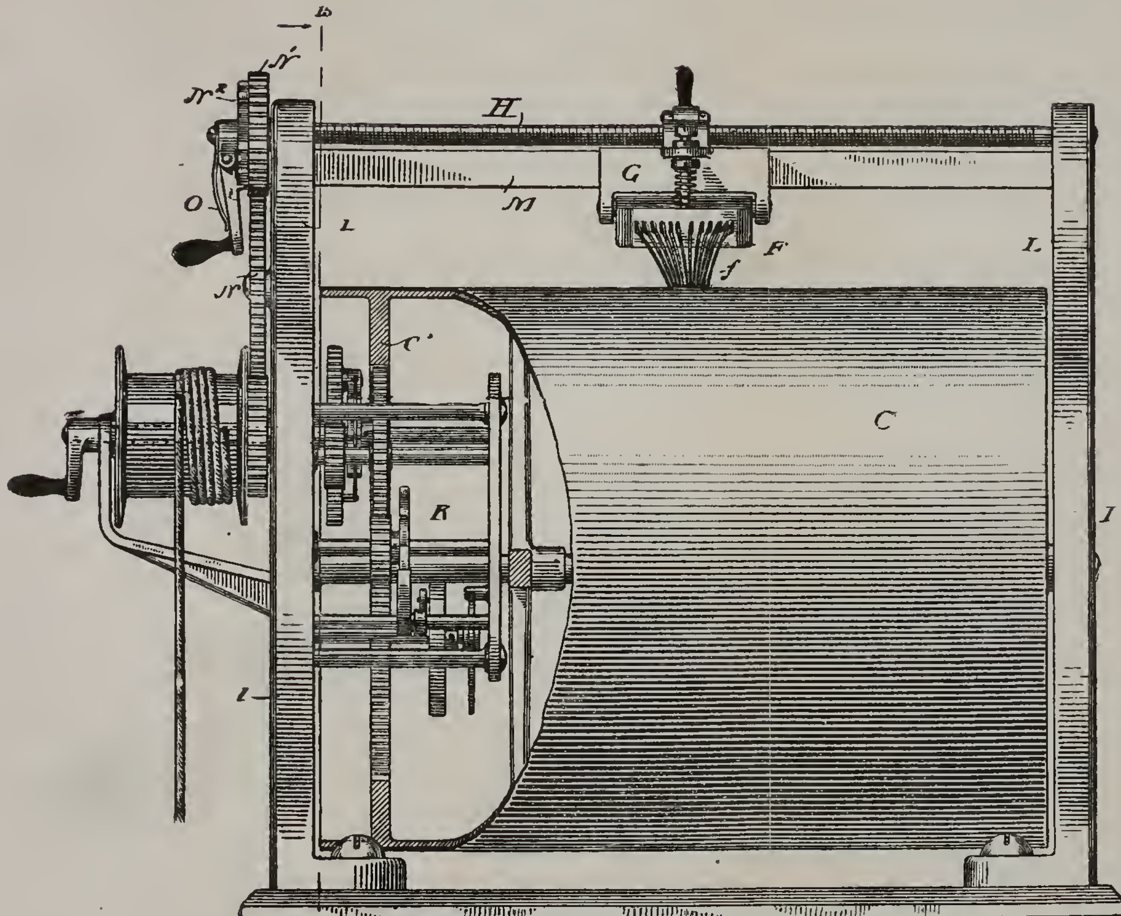



FIG. 7. Device for Rotary Motion of Transmitting and Receiving Apparatus.

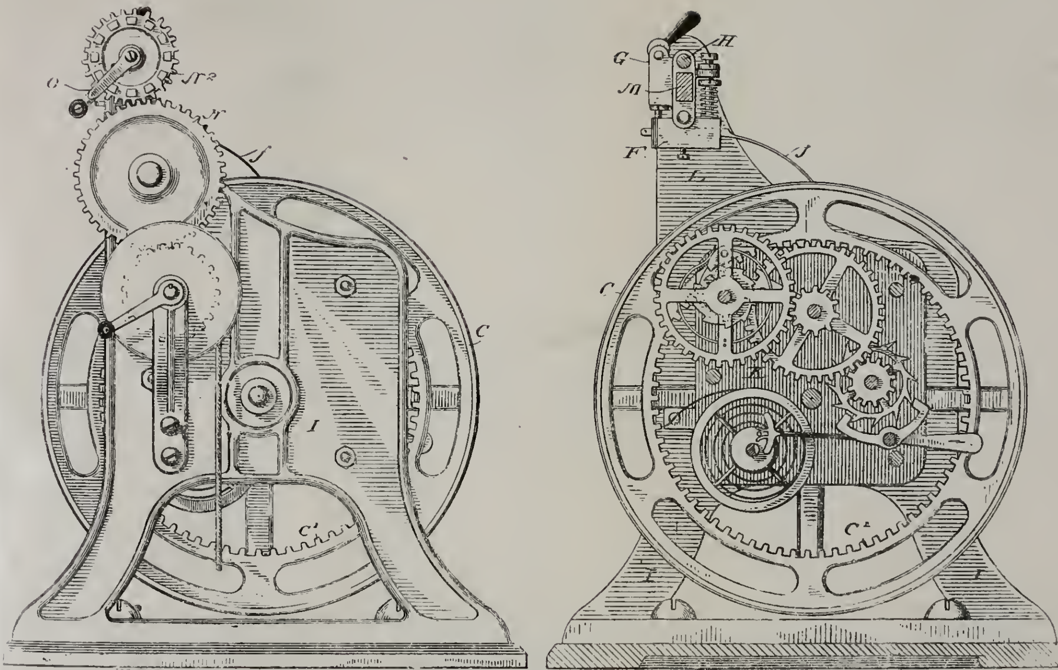
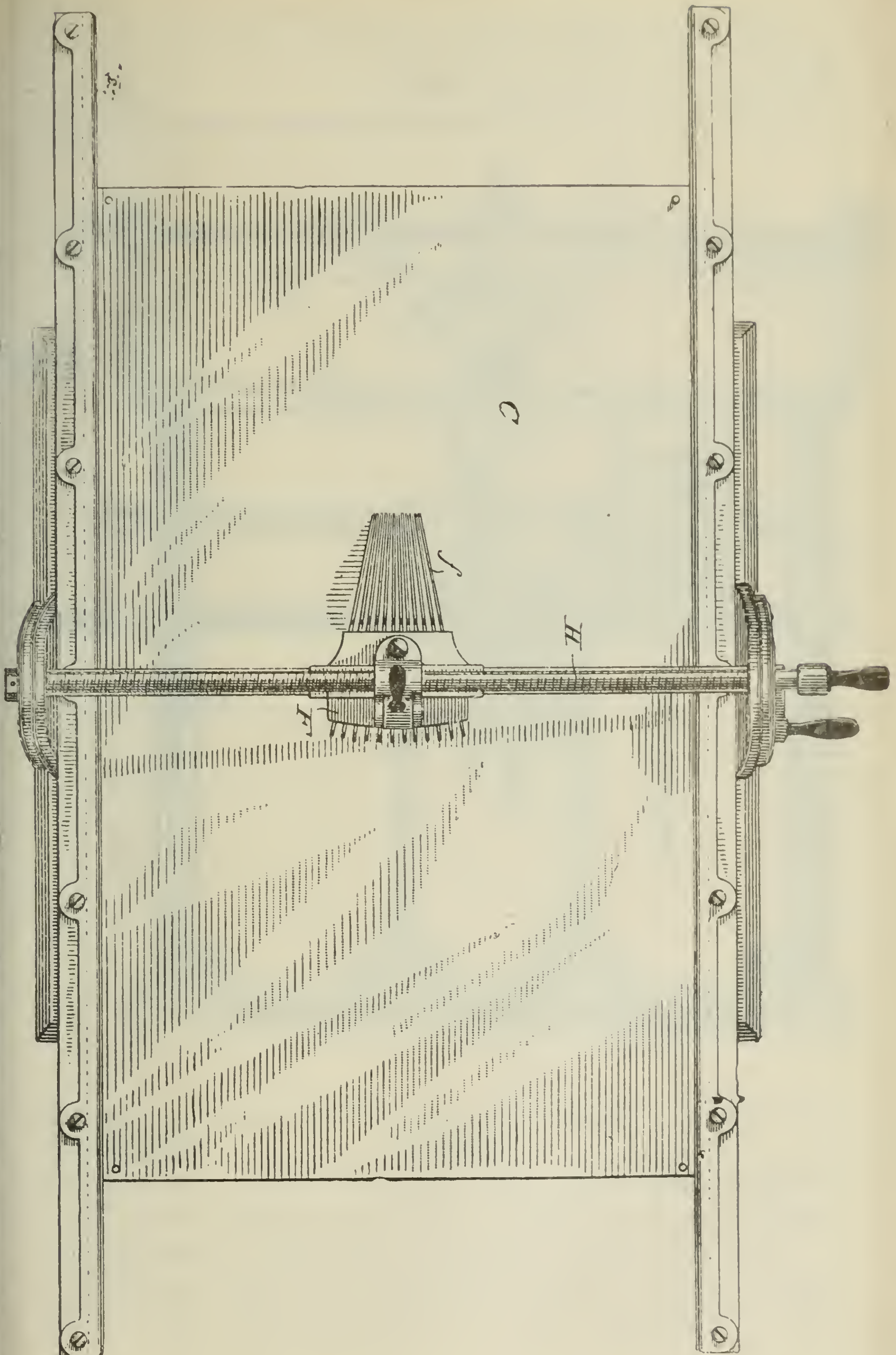



FIG. 8. Device for Rotary Motion of Transmitting and Receiving Apparatus.


H

The locking of the wheel $N^1$, on the shaft $H$, causes this shaft to move as the cylinder is rotated, and so moves the comb laterally over the cylinder as the latter revolves.

Mr. Delany has devised the following means for reproducing the

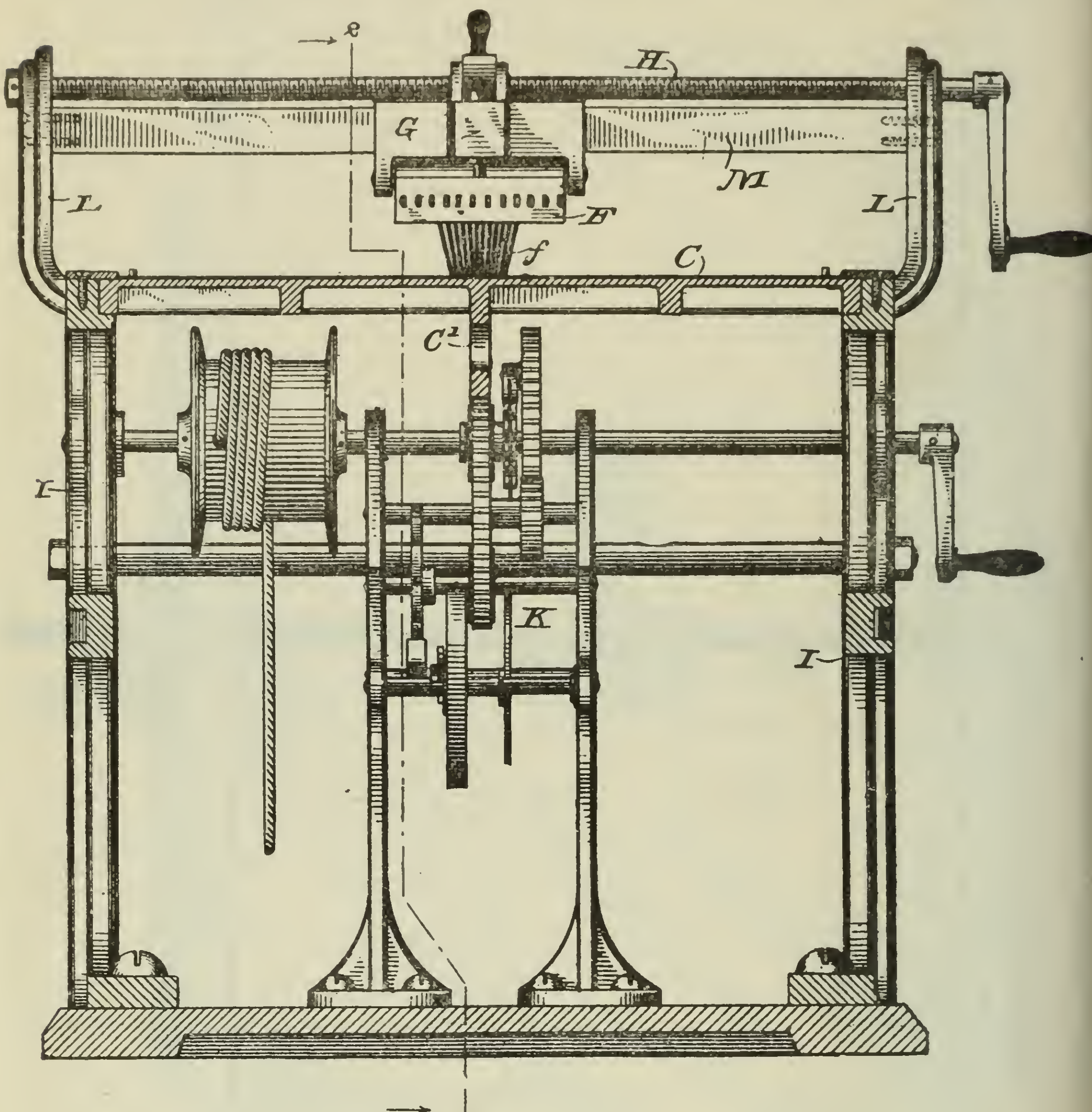



FIG. 6. Device for Reciprocating Motion of Transmitting and Receiving Apparatus.

fac-simile despatch by means of a local battery. The apparatus required for this purpose is shown in connection with *Fig. 9.*

In this drawing only one stylus in the comb $f$, is represented as connected in the circuit for the purpose of avoiding the multiplication of unnecessary lines. The local batteries $L, B$, at $X$, and

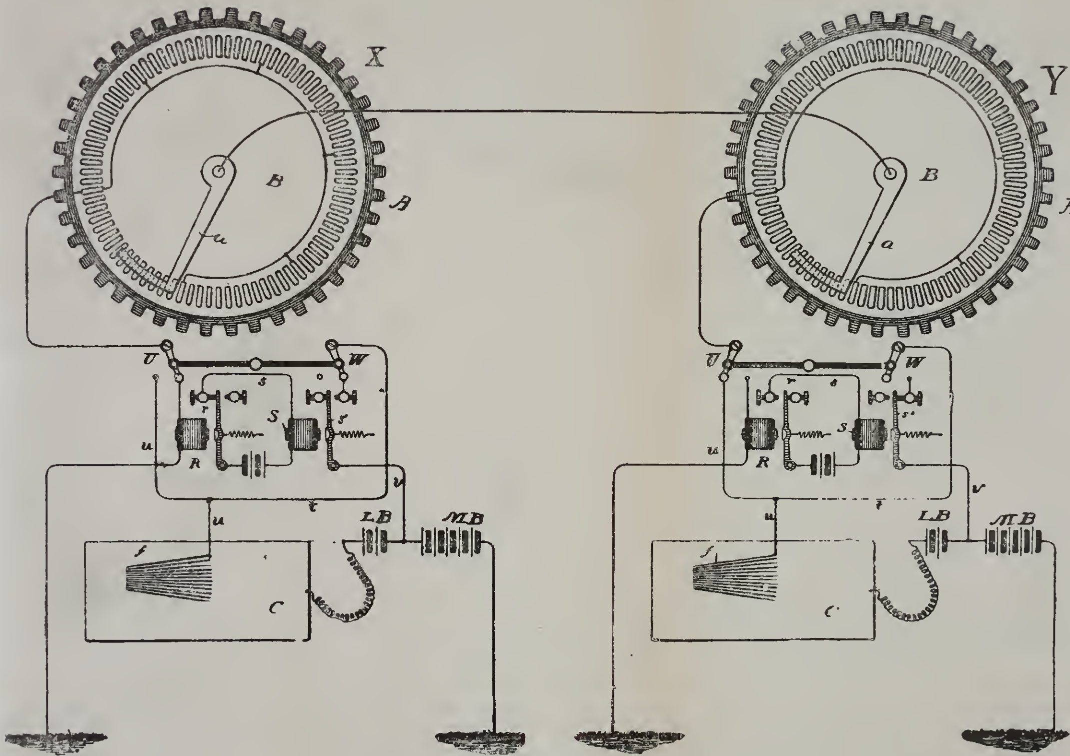



FIG. 9. Fac-simile Reproduction by Local Battery.

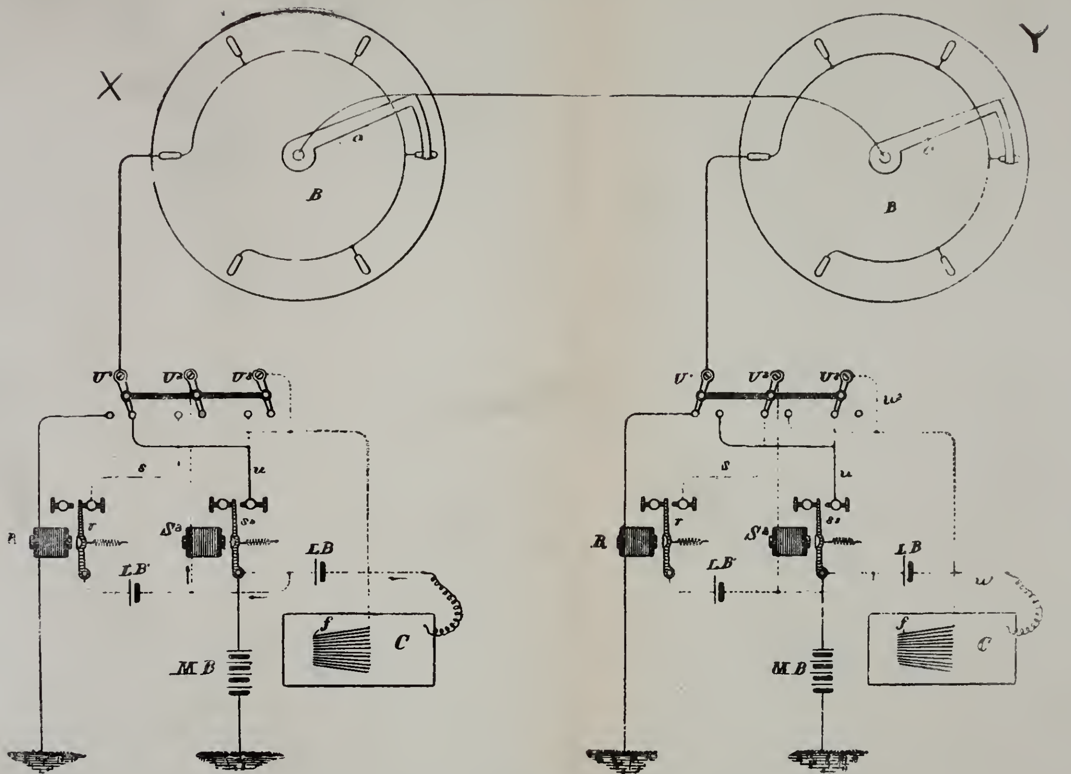



FIG. 10. Fac-simile Transmission. Improved Apparatus.

*M*, *B*, at *Y*, the transmitting station, connected as shown, send their current through the plate *C*, finger of the comb *f*, line *u*, switch *U*, to the table of circular contacts on *B*, and thence to the main line; the local circuit *t*, and the branch *v*, being both open.

At the receiving station *X*, the switch *U*, is connected with the coil of the relay *R*, and *W*, in connection with the back-contact of the armature $s^1$, of the magnet *S*. When the current that passes over the main line from *Y*, flows through the electro-magnet *R*, it energizes its core and attracts the armature and draws it against its front stop. Since the transmitting battery at *Y*, is sending its impulse into the main line at the rate of about eighteen per second. the armature of *R*, has no time to leave its front stop and is therefore constantly drawn against it, thus completing the local circuit *s*, of the magnet *S*, and drawing its armature $s^1$, against its front stop.

Suppose now the receiving surface at *C*, is covered with a sheet of Bain paper, and that a message is written in non-conducting ink on the transmitting surface at *Y*, then as long as the main current is passing over the main line at the rate mentioned, no marking will be produced on the receiving surface at *X*. When, however, the trailing finger *f*, comes in contact with the non-conducting line traced on *C*, at *Y*, the battery current over the main line is interrupted for a sufficient length of time to permit *r*, under the action spring, to come against its back-stop, break the circuit *s*, and permit $s^1$, to move against its back-stop. Under these conditions, the circuit of the local battery *L*, *B*, will be completed through the receiving plate *C*, as follows, viz.: from the battery through *C*, "finger *f*, line *ut*, switch *W*, armature $s^1$, line *v*, to the opposite pole of the battery;" and thus effect a coloration in the paper covering the plate *C*.

In this manner the design traced on the surface *C*, at *Y*, is reproduced in colored lines on the otherwise white surface of the paper that covers the surface of the receiving apparatus.

The form of apparatus, however, which Mr. Delany prefers, is shown in connection with *Fig. 10*.

As shown in this figure the switches $U^1$, $U^2$ and $U^3$, at each end of the line, are arranged for transmission from *X*, to *Y*. As before connections with a single group of contacts only is shown.

The transmitting battery *M*, *B*, has one of its poles connected

to ground and its other pole to the armature $s^2$, and the magnet $S^2$. The front stop of this armature is insulated ; its back-stop is connected to the main line, through the line $u^1$, switch $U^1$ and the circular table of contacts. The local battery $L$, $B$, has its circuit closed under normal conditions through the path indicated by the arrows. The armature $s^2$, is therefore drawn against its insulated front stop, whenever the circuit between the finger $f$, and the plate $C$, is uninterrupted. When, however, this circuit is broken or interrupted by the finger $f$, coming in contact with the non-conducting ink on transmitting surface at $X$, this local circuit is interrupted, $s^2$, moves to its back-stop and the current from the main battery $M$, $B$, will pass through the line $u^1$, switch $U^1$, and over the main line to $Y$. When, after passing through the contacts and the switch $U^1$, it flows through the coils of $R$, and thence to earth. The armature $r$, of magnet $R$, is thereby drawn against its front stop, thereby breaking the circuit of the local battery $L$, $B^1$, which normally is completed through $r$, line $s$, switch $U^2$ and magnet coil $S^2$. When the impulse sent from $X$, breaks this circuit in the manner described, the armature of $S^2$, moves against its back-stop, thus completing the circuit of the local battery $L$, $B$, through the armature $s^2$, line $u^1$, switch $U^3$, $u^2$, $f$, and plate $C$. If, therefore, the surface of the receiving apparatus is covered with a sheet of Bain paper, a discoloration is produced thereon, which reproduces the design traced on the transmitting apparatus.

From this brief description of the apparatus which the author has drawn mainly from the United States Letters Patent before referred to, it will readily be seen that Mr. Delany has produced a system of fac-simile telegraphy that possesses all the requisities for successful commercial application.

CENTRAL HIGH SCHOOL,
Philadelphia, May 18, 1885.

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ATMOSPHERIC CURRENTS.—A balloon ascension by the Tissandier brothers showed some interesting particulars in regard to the stratification of aërial currents. For 800 metres above the earth's surface the wind blew from the southeast ; at the upper surface of the fog there was a counter-current, with a thickness of about 350 metres, from the northwest. At a still greater height there was a third current from nearly the same direction as the surface wind. The currents were all feeble, and the balloon went back and forth over Paris in precisely opposite directions.—*Les Mondes, Nov. 8, 1884.* C.

# The TATHAM DYNAMOMETER.

The Tatham dynamometer, constructed for the Franklin Institute last year, which measured the power consumed by the dynamo-electrical machines tested by a Committee of Judges in June last (see report in Supplement to the Journal of the Franklin Institute, for November, 1885,) is capable of measuring 100 horse-power. The largest machine then measured required 70 HP.; the smallest ·23 HP.

It occupies a floor space of about 6 feet by 4 feet, and is about 7½ feet high.

The cast iron bed-plate rests upon heavy castors and is provided with levelling screws. Upon this bed-plate are erected the two main frames, bolted together at convenient places and united at the top by a cast iron arch, from which the scale beam is suspended. A movable *A* frame in two parts is hinged to the bed-plate, and when in position, holds firmly the journal boxes of the outside bearings of the two middle shafts. When opened, it gives liberty to change the outside pulleys, or the belts which run upon them.

This dynamometer is upon the same principle as the small machine described in the Journal of the Franklin Institute, for December, 1882, but differs from it, in that the single pulley upon the first motion shaft of the small machine is replaced by three pulleys in the large one.

(Reference being had to the skeleton sketch herewith) the reasons for this change were:

(1.) To reduce the height of the machine.

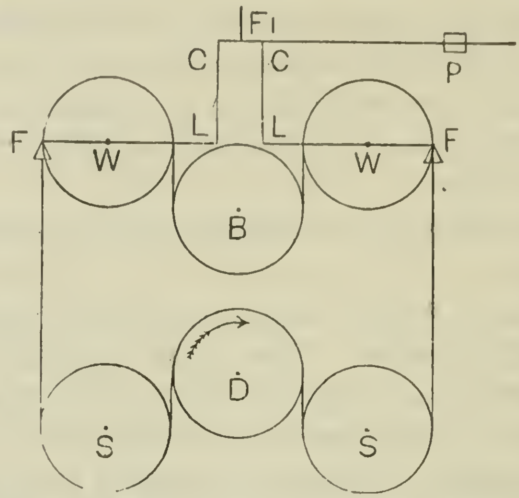
(2.) To give the journals of the pulley shaft *D* a fixed position, while the two outside lower pulleys are used to tighten the belt.

(3.) To make the two pulleys *B* and *D* run in the same direction and with the same speed.

All of the pulleys are cast iron plate pulleys, turned all over inside and out and accurately balanced. They are twelve and a-half-inches face and are upon cast steel shafts, two-inches diameter, running in brass boxes, which are from six to eight inches in length.

The pulley *D* is twenty-five-inches diameter, crowned and placed upon the first motion shaft, which receives power from an outside

belt. The pulley *B*, twenty-five-inches diameter, ground perfectly true and flat, is upon a shaft which conveys the power to the machine to be tested. In measuring a motor, its power is applied to the pulley *B*.




The two pulleys *S* and *S* are crowned, twenty-one-inches diameter and their shafts run in bearings which are upon vertical slides regulated by screws. The vertical movement of these pulleys regulates the tension of the belt. The pulleys *W* and *W* are twenty-one-inches diameter, slightly crowned, and their shafts run in bearings upon the two lever frames *L F* and *L F*, each of which has its fulcrum in a pair of knife edges at *F*, resting upon the main frame. The inside ends of the lever frames are suspended by links *L C* and *L C* to the scale beam *F P* at equal distances on either side of the principal centre of the beam. There are two adjustments to each of these lever frames. (1.) Two micrometer screws adjust the position of the centre of the pulley, so that the line of effect of a belt hung on it on the outside will pass through the fulcrum, and no addition of weight to the belt will affect the scale beam; which is experimentally proved. (2.) The position of the knife-edge suspended to the link is adjusted so that the scale beam weighs accurately any weight suspended by a piece of belt hung over the inside of the pulley.

The endless belt used was a four-ply gum belt, 12-inches wide and ·26-inches thick. The breaking strain was 12,000 pounds. It was originally intended to use a three-ply belt, ·21-inches thick, and the pulley *B* was constructed so that the effective diameter would be 25·21 inches, giving a delivery of belt of 6·6 feet per revolution. The arrows indicate the movements of the belt.

It will be seen by the construction, that the pulley $B$ is actuated by the difference of the tensions of the two parts of the belt tangent to it, and that the scale beam weighs the same difference of tensions of the same parts tangent to the pulleys $W$ and $W$.

As the accuracy of weighing was the vital requisite, the construction of the dynamometer was intrusted to the celebrated scale makers, Messrs. Fairbanks & Co. The scale beam was graduated by Messrs. Brown & Sharpe in 600 divisions of $\frac{1}{15}$ inch each representing a half pound with the travelling poise used. On this poise is a small beam graduated in hundredths, so that the small poise upon the small beam is capable of weighing $\frac{1}{200}$ of a pound when the machine is in motion. The more rapid the motion the more delicately can the weighing be accomplished.

In testing dynamo electrical machines, the resistance measured being very uniform, it was only necessary that the belts used should be of even thickness and free from lumpy splicings, to get rid altogether of the tendency to dance, which otherwise afflicts the beams of belt dynamometers

The fastest speed made by the dynamometer in June last was 1,700 revolutions per minute, which gave the belt a speed of two and one-eighth miles per minute, or about one-eighth the velocity of a rifle ball. The fastest speed of any test was about 1,400 revolutions (9,240 feet of belt) per minute continued for ten consecutive hours, during which the belt ran over 1,000 miles.

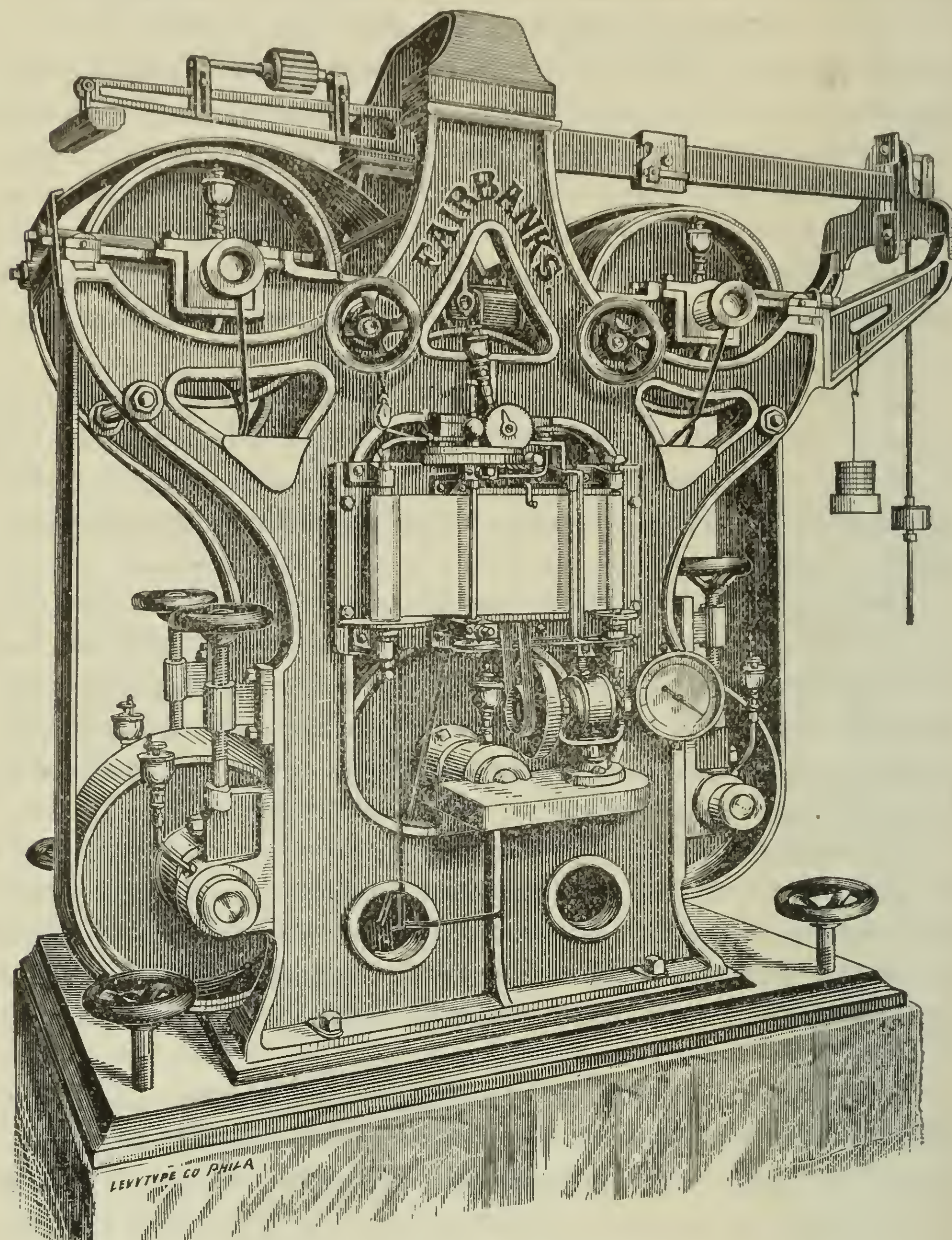
The centrifugal force tending to break the belt at this speed, is about 1,350 pounds on each part, but this force does not come on the journals or pulleys: it is confined to the belt itself, and stretches it, until it becomes slack. The slack is taken up by screwing down the pulley $S$, or $S$, and when the machine slows or stops the belt *is* tight.

In getting the "friction" of the pulley $B$, after a test, the machine was run light at the same speed that it had run loaded during the test; thus comprehending in similar measure all sources of resistance whether from friction proper, bending and straightening the belt, or air currents. The force required to bend and straighten the belt was sensibly affected by the temperature of the air.

Before the dynamo tests began, it was observed that the air currents, caused by the rapid movement of the belt, interfered with

the functions of the scale beam, and it was found necessary to place sheet iron roofs over the upper pulleys. The lubrication is accomplished by an automatic feed, under control.

The machine is provided with a counter, which registers the




The Tatham Dynamometer.

number of revolutions up to 1,000,000. The number of revolutions per minute can be observed to within a fraction of one revolution.

It is also provided with apparatus to record the power measured. This, however, was not used during the tests, as direct weighing

was found so convenient, and the results could be so quickly calculated. At the end of the scale beam is a vertical rod attached below to an iron cylinder, which floats in mercury in an iron cylindrical pipe. The beam being balanced, any force tending to raise it, lifts the cylinder out of the mercury proportionally. This motion, multiplied by levers, is communicated to a pencil point, which moves vertically one-eighth of an inch to the pound, and records the weight upon a paper band moving horizontally one inch for every 100 revolutions, and recording them. This automatic registration of weight is applied only to the fractions of weight between the even fifty pounds, the principal part of the weight being hung at the end of the scale beam in the usual way.

By confining the registration to this small excess, it is registered on the large scale above mentioned. The calculation of HP measured is very simple. Multiply the number of revolutions by the weight (in one-half pound) on the scale and divide by 10,000. The result is HP and decimals This, however, supposes a belt twenty-one hundredths of an inch thick. A thicker belt requires a correction in accurate work.

Not the least interesting portion of the report of the Committee referred to, is that relating to the "Calibration of the Dynamometer." In order to prove whether or not the dynamometer measured correctly the power transmitted through it, it was used in the determination of the mechanical equivalent of heat on an enormous scale. The water churn used was a cylinder, 3 feet diameter and 3 feet long, holding 1,223 pounds of water. In the continuous method, devised by Professor Marks, the water entered the churn at nearly uniform temperature and left it at nearly uniform temperature, about 15·5° Centigrade higher than it entered. The operation continued for three hours. The first half hour was occupied in bringing the exit water to uniform temperature, when the experiment proper began and continued for two hours and a-half, during which over five tons of water passed through the churn and was raised about 15·5° Centigrade by the continued exertion of about forty-six horse-power.

The result as calculated was:

Mechanical equivalent for 1° Centigrade, . . 1391·05 foot pounds.
Mechanical equivalent for 1° Fahrenheit, . . 772·81 foot pounds.

Dr. Joule's last determination was 772·55 foot pounds, and Prof. Rowland's is higher. W. P. Tatham.

## THE BEHAVIOR OF STEAM IN THE CYLINDER.

THE COMMITTEE ON PUBLICATIONS:

*Gentlemen:*—I observe in Chief Engineer Isherwood's account of certain experiments on steam engines, published in your latest issue, that he continues to claim the "discovery that the cylinder of a steam engine acted alternately as a condenser and as a boiler, condensing a portion of the entering steam during its admission, and revaporizing the resulting water of condensation during the period of expansion and during the exhaust stroke, which phenomena were caused wholly by the interaction of the metal of the cylinder," etc. "This discovery," he says, "was made a great many years ago by him, and stated and used in his published professional writings," and he refers to his "Engineering Precedents," Vol. II., 1859; and to his "Experimental Researches in Steam Engineering," 1861 and 1863. He adds, that "no one contested the discovery, or even used it until quite lately." I presume he herein alludes to my paper, "On the Behavior of Steam in the Cylinders of Locomotives during Expansion," published in the minutes of "Proceedings" of the Institution of Civil Engineers, England,* of which I enclose to you a copy; and this reference must be my apology for asking you to publish this letter in reply.

In the copy of my paper enclosed, I have summarized the results of my experimental investigations on the action of steam in the cylinder, which were conducted in the year 1850, and the results of which were published in the course of the year 1852†, or seven years before Mr. Isherwood even made or published his experiments bearing on the question. In the enclosed paper, I have briefly restated the evidence and arguments employed and published by me in 1851–52, in investigating the behavior of steam in the cylinders of locomotive steam engines, showing, amongst other things, the formidable losses by condensation and re-evaporation of steam in cylinders, and the augmentation of the

* See Vol. lxxii, of the Minutes, Session, 1882–83, page 275.

† See *Railway Machinery,* 1851–56. Blackie & Son, pages 77 to 85; also a paper on the "Expansive Working of Steam in Locomotives" in the "Proceedings of the Institution of Mechanical Engineers," 1852, pp. 63, 105.

loss in proportion to the degree of expansion to which the steam is worked; and showing that without the adoption of special means for preventing or lessening condensation within the cylinder, expansive working, by cutting off earlier than from one-half to one-third of the stroke could not be practised with economy. If you will allow me, I will quote a paragraph direct from *Railway Machinery*, in which I specially announce what Mr. Isherwood calls *his* discovery seven years before he made or published his experiments.

"In general, it is to be concluded that, first, when the cylinder is thoroughly immersed in the hot bath of the smoke box, the temperature of which is commonly much higher than that of the steam, the quantity of water existing as steam during expansion is virtually constant. Secondly, when the cylinder is placed nearly or entirely beyond the influence of the heat of the smoke box, or is protected only in the usual manner by felting and plating, the quantity of water as steam varies very considerably during expansion. It suffers a rapid and transient diminution during the first stages of expansion, and amounts to an excess over the initial quantity, which increases uniformly as the ratio of expansion is prolonged; till for a final volume of about three and a-half times the initial volume, when the steam is cut off at fifteen per cent., the excess amounts to fifty-seven per cent. of the weight of sensible steam cut-off, or otherwise to thirty-six per cent. of the gross quantity of steam admitted. The foregoing results are directly contrary to what might have been anticipated as, at first sight, they appear to show that the less protected the cylinders, the more work is done with a given initial quantity of steam. In the inside cylinder, so far from any apparent evaporation or accession to the total weight of the steam during expansion, the quantity is at least not more than constant, and is, in fact, slightly reduced during expansion. The outside cylinders on the contrary show, by the great excess of steam at the end of expansion, very significant amounts of factitious evaporation. In this case, as in that of the low speed diagrams, the difference is referable to a primary condensation of the steam during admission, by which water is formed, whilst the temperature of the cylinder is raised. After suppression, and when the steam temperature falls by expansion below the newly-acquired temperature of the cylinders, the hot water flashes into steam in

virtue of its own heat and that of the cylinder, according to the law of the maximum density and pressure for the temperature; and what appears, at first sight, to have been positively one advantage of unexposed cylinder, in the auxiliarly evaporation during the later stages of expansion, is nothing more than a partial resuscitation of the precipitated steam, as a compromise for lost initial action. The greater the proportion of expansion, the greater is the final excess of steam, as the extreme temperatures become more widely different; and, moreover, for the higher degrees of expansion smaller absolute volumes of steam are admitted, for which there is always the same cooling superficies of cylinder; and this is relatively greater, of course, as the period of admission is reduced. In the enclosed inside cylinder, on the contrary, bathed in hot air, or enveloped in cinders, actually hotter than the steam that passes through them, the initial pressure of the steam as it enters the cylinders, is maintained in its integrity, as, even for the greater expansions, there appear no symptoms of a resurrection of steam. The evidence goes rather to show that the steam is superheated during its passage through the steam pipes previous to admission."*

I have supplied direct evidence of alternate condensation and re-evaporation by direct comparison of the quantity of steam cut off, according to the indicator diagram, and the quantity of water measured from the tenders of locomotives—not necessarily in terms of their weight, as Mr. Isherwood appears to insist on, but in terms of the volume of water, as steam and water from the tender, which are, of course, exact measures of quantity. In fact, measurement by volume is the basis of the investigation. If, as he implies, he weighed the sensible steam, how did he weigh it? And if he did weigh it, why is weight a better measure than volume? I have given very full details of experiments and observations on the performance of locomotives to prove by direct measurement, quantitatively as well as qualitatively, the pregnant fact of the alternate condensation and re-evaporation of steam. In the case of No. 42 express locomotive on the Caledonian Railway, in 1850, and several other locomotives. The results were published in detail in 1852.†

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* *Railway Machinery*, page 82.

† See *Railway Machinery*, 1850–56, pages 144 to 151; also, "Proceedings of the Institution of Mechanical Engineers," 1852, pages 120 to 126.

Then Mr. Isherwood says: "No one contested the discovery, or even used it, until quite lately." I may say, for my part, that since the first publication of my experiments and deductions, in 1851–52, I have repeatedly announced the fact of alternate condensation and re-evaporation as a matter first demonstrated and established by myself.* Mr. Isherwood appears, also, to forget his correspondence with Mr. G. A. Hirn, in 1879, respecting the claim of Mr. Isherwood, in the JOURNAL OF THE FRANKLIN INSTITUTE, for July, 1878, to his having published for the first time his "discovery." M. Dwelshauvers Dery published the correspondence in 1879,† from which it appears that Mr. Isherwood was anticipated by Mr. Hirn, by several years, in 1857, although Mr. Hirn was again anticipated by me in 1851–52. Mr. Isherwood is therefore in error in stating that "no one contested the discovery."

As the question of prior discovery has been raised, perhaps, Gentlemen, you will allow me to quote a disinterested authority, Mr. Anatole Mallet, past President of the Institution of Civil Engineers of France, who has kindly recognized my priority on this question in his communication to that institution in 1877, on the utilization of steam in locomotives: *Etudes sur l'Utilization de la Vapeur dans les Locomotives et l'Application à ces Machines du Fonctionnement Compound*," in the *Mémoires de la Société des Ingénieurs Civils*, 1877. In this paper, Mr. Mallet says: "Mr. D. K. Clark was the first experimentalist who, by practical evidence, traced to its true source the excess of the quantity of steam; or the water equivalent of it, in the cylinder, at the end of the expansion. He demonstrated that a portion of the steam, when admitted at each stroke, was condensed, and that it was in part re-evaporated at the end of the expansion; and that by this destroying process, the efforts at economy by cutting off early and expanding were baffled, insomuch that it was practically impossible with economy to cut off earlier than at one-third of the stroke." Mr. Mallet proceeds to say: "In these publications (already named in the second foot note), has been for the first time so

* See *The Exhibited Machinery* of 1862, page 300; *Steam and the Steam Engine*, 1875, page 267; *A Manual of Rules, Tables and Data for Mechanical Engineers*, 1877, page 880.

† See *Revue Universelle des Mines*, vol. v, 1879, page 494.

completely elucidated the behavior of steam in the cylinders of locomotives, and the part that is played by the condensation of the steam during admission—a characteristic phenomenon which gives the key of the difference which always exists between the practical expenditure of engines and the calculated consumption, and the reality of which, strange to say, many engineers, otherwise very distinguished, really believed, could be contested ten or twelve years after the publication of these works" (p. 852).

See a series of articles in behalf of Mr. Hirn's claim, on "Les Decouvertes Récentes Concernant la Machine à Vapeur,"—"Recent Discoveries in the Steam Engine," by M. Dwelshauvers Dery, in the *Revue Universelle des Mines*, tomes iv., v. and vii., for 1878, 1879 and 1880. Also several contributions by Mr. O. Hallauer, and others, to the *Bulletin de la Société Industrielle de Mulhouse*.*

D. K. CLARK.

8 BUCKINGHAM STREET,
ADELPHI, LONDON, ENGLAND,
October 22, 1885.

## BOOK NOTICES.

SPECIALISTS' SERIES, VOL. 2.—GAS ENGINES. By Wm. Macgregor. Price, $3.00. London: Symons & Co.; New York: D. Van Nostrand.

This is an unusually satisfactory addition to the technical literature of the day.

The progress of invention, from the early attempts to produce a successful motor by the combustion of gunpowder, and of hydro carbons—to the more recent inventions of Clerk and Otto, is clearly traced.

The explanation of the mechanical construction and theory of each type of engine is clear and satisfactory.

Seven plates are appended, which contain forty-one sections, and explanatory views, including indicator diagrams.

Chapter 9, pp. 210 to 225, contains a condensed synopsis of a paper by Prof. W. E. Ayrton, F.R.S., and John Perry, M.E., read before the Physical Society of London, "intended to teach practical men a method of obtaining information from the indicator diagrams of a gas engine." Taking the Otto engine, as typical, its action is explained through a single cycle of its operation, the indicator diagram, and its uses are also explained fully.

The nature of the working fluid is shown by tables constructed by Messrs. Ayrton and Perry, followed by careful analysis of the diagram tables, etc.

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*In a letter received since above was in type, Mr. Clark makes the following additional references to establish his claims to priority, viz., A Rudimentary Treatise on the Steam Engine, 1879, Lockwood & Co.; and the article, Steam Engine, Encyclopædia Britan., eighth edition. [Com. Pubs.]

The stimulus given to everything relating to the uses of gas by the success of the electric light, has resulted in the invention of a number of gas engines, some of them of remarkable merit. To enable mechanical engineers to correctly proportion and build these machines, such a work as this was much needed, and will result, doubtless, in the production of still better engines than those now in operation. M. G. W.

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A Catalogue of Chemical Periodicals. By H. Carrington Bolton, Ph.D. From the Annals of the New York Academy of Sciences. Vol. iii., Nos. 6 and 7.

In this catalogue may be found a very full list of the titles of the principal chemical periodicals of twelve countries. The titles of some periodicals that pertain also to pharmacy, physics and the application of chemistry to the arts and manufactures are found in the list. The author has endeavored to furnish a complete bibliography of periodicals devoted chiefly to chemistry and refers any one desiring a more comprehensive bibliography of scientific works to his *Catalogue of Scientific and Technical Periodicals, 1665–1882*, published by the Smithsonian Institution, or to the *Catalogue of Scientific Serials*, by Mr. S. H. Scudder (Cambridge, 1879).

The arrangement of titles is alphabetical, with full and useful cross-references. A geographical index of countries and cities is added.

The value of Dr. Bolton's useful work will be recognized by all chemists, but can be fully appreciated by those alone who have learned by experience how much such catalogues and special indexes are needed. L. B. H.

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A Manual of the Theory and Practice of Topographical Surveying by Means of the Transit and Stadia. By J. B. Johnson, C. E.

This is a much needed work. The methods treated of have long been commonly used in Europe; but, although adopted here upon some important government and other surveys, their use has been chiefly restricted to a few engineers engaged upon such work, and whose occupation has justified them in specially investigating the subject. The accounts of these surveys, which have from time to time appeared in the engineering periodicals, have elicited a growing demand for a comprehensive treatise upon the subject; a demand which has hitherto remained unsatisfied, unless we except the little book of Mr. Winslow, lately reprinted from *Van Nostrand's Magazine*.

The present volume goes a great way toward supplying this "long-felt want." The needed information is given with great conciseness, and yet with a fulness sufficient for those acquainted with the ordinary methods of topography, and for these the book is intended.

The few formulæ given cover the case completely, and are so simply and clearly put as to be easily understood and memorized.

The author has been remarkably successful in accomplishing, within the narrow limit of about 100 pages, his three-fold object, as stated in the preface: first, to instruct the student, and afterward to aid him in the field; second, to furnish the practising engineer with such an account of the theory and method as would enable him, "without other instruction," to "prepare his instruments and do the work in good shape;" and, third, to furnish the necessary reduction tables and directions for plotting.

The first chapter gives the theory of stadia measurements, with the necessary formulæ for obtaining, at one sight, horizontal angles and distances, and elevations. The second describes the instruments used, the transit and the stadia, with the features required and desirable to adapt the former to this method of work. The third explains the application of the method to general topographical surveying, including the field work, the reduction and plotting of the notes, and the final preparation of the map. The fourth gives corresponding instructions as to railroad work, and the fifth as to other surveys, such as those for canals, drainage basins, bridge and town sites, geological surveys, etc. The sixth and seventh chapters give briefly some data as to the probable accuracy and cost of the survey with transit and stadia, and a comparison of the relative advantages of that method with those of the use of the plane table. The eighth chapter, treating of baseline measurement, triangulation and azimuth, seems properly a part of, or supplement to, the preliminary part of the third. The ninth and last chapter is devoted to the preparation of the map.

If we were asked to name a desideratum for a second edition, we should ask for more numerous and better cuts. These would not only make the book much more easy of use to the engineer, but would open it to a large class of students to whom much of the letter-press must now be "Greek."

While fully realizing, not only from the author's pleading, but from our own experience, the very decided advantage of the method here described, we are inclined to make the comparison between it and plane table-work rather less unfavorable to the latter. The author, we should say, gives too little weight to the advantage of field plotting as a guard against errors; and does not refer to the employment of a separate levelling instrument in the hands of a leveller who directs the rodman, which is so generally and so advantageously used in connection with the plane table.

The relative claims of the two methods are, however, as the author says, "a question every engineer must decide for himself," and we can heartily commend this book to the engineering fraternity both practitioners and students, as a highly satisfactory exposition of the subject. T. H.

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A Treatise on Friction and Lost Work in Machinery and Mill Work. By Robert H. Thurston, A. M., C. E. New York: John Wiley & Sons, 1885.

This is one of the works that place the public under obligation to their authors. In it, Professor Thurston lays before us the abundant fruits of years, of intelligent and pains-taking study and observation. The present work covers the same ground as the author's earlier treatise,* but with much greater fulness, in general and in detail. It might indeed have been, with propriety, and to the improvement of its title, announced as a greatly enlarged edition of the former work.

The first chapter is a brief glance at the general theory of machinery, including force, power, work, energy, efficiency and lost work.

The second takes up the theory of friction in detail, giving special prominence to the friction of journals and pivots, but embracing also that of wedges, pulleys, wheels, earth, etc., and of fluids.

* "Friction and Lubrication," published by *The Railroad Gazette*, New York, 1879.

The third is an exceedingly satisfactory description of the lubricants themselves, animal, vegetable and mineral; solid, semi-solid and liquid, with their several excellencies and defects, their most frequent adulterations, etc.

The fourth is devoted to the very important subject of the methods of applying lubricants; upon which, more perhaps than upon any other feature, the value of lubrication is shown to depend. The various methods in use are described, and their respective merits and demerits discussed. Strangely enough, we find but a very incomplete description (without cuts) of the *oil-bath*, which is frequently referred to throughout the book as being by far the most perfect device for reducing friction.

The fifth chapter is an eminently practical treatise upon the testing of lubricants. It is full to the brim with most useful tabular and other information. It should, we think, as a matter of arrangement, have contained the description of the author's pendulum testing machine. This, with similar accounts of other machines, we find, rather out of place, in the sixth chapter, along with the recital of many of the earlier and later experiments on friction.

The seventh chapter is exceedingly valuable; giving, as it does, the behavior of all sorts of lubricants under all sorts of conditions, as determined by the most recent and exhaustive experiments, mostly made by the author with the testing machines designed by myself and already referred to. Many of the results here announced are quite at variance with those published by earlier experimenters; particularly in the matter of the effect of pressure. The author found much higher coefficients under low pressures, and much lower ones under high pressures, than did his predecessors; and, generally, much greater variations of the coefficient with pressure, velocity and temperature. Most interesting diagrams are here given, showing the effects of these three elements upon the coefficients obtained with a given lubricant; and their interdependence upon each other.

The eighth, and last, chapter, a bright one, proposes a theory of the finance of lost work, and a method for the determination, by formulæ, of the commercial values of lubricants. It is not denied that the difficulty of obtaining the required data for these formulæ is very great, and at times insurmountable; but where these can be approximated with confidence, the use of the formulæ (which are quite simple) ought to lead to important economies.

The index is rather meagre, but is admirably arranged, both the number of the *article* and that of the *page* being given for each subject.

If there is a fault in this work, it arises from the intimacy of the author's acquaintance with his subject, which seems to lead him at times to forget the necessity for extreme care as to the way of stating things. As a good lubricant may, through a faulty method of application, fail to give its best results, so even the bountiful feast of reason which the author here spreads, might, we think, have been made more inviting by closer attention to detail in the serving up. Merely as an instance, we note the following sentence on page 139: "Economy is best secured where the dripping oil is not preserved by any arrangement which furnishes the lubricant in a perfectly uniform supply and in minimum safe quantity." True, the reader soon finds that commas (or, still better, the old-fashioned parentheses) are needed after "secured" and after "preserved," but the meaning would have been plain at once if

the sentence had begun with the parenthetical clause, "where the dripping oil is not preserved." These little matters often make the difference between a readable book and a "tough" one.

But where the recognized authority upon a difficult subject like this, gives to the fraternity so solid a mass of valuable fact as in this case, it is hardly in order to cavil over details; and we have no doubt the fraternity will substantially express its obligation by eagerly using what is set before it.

T.

## Franklin Institute.

[*Proceedings of the Stated Meeting, held Wednesday, September 16, 1885.*]

HALL OF THE INSTITUTE, September 16, 1885.

MR. WM. P. TATHAM, President, in the Chair.

Present—Fourteen members.

The election of forty new members was reported.

The Secretary reported a recommendation from the Committee on Science and the Arts, for the award of the JOHN SCOTT Legacy Premium and Medal to P. E. JAY, of New York, for his Automatic Anti-Freezing Valve for Water Pipes. The recommendation was approved, and the Secretary was directed to inform the Committee on Minor Trusts of the Board of City Trusts of the action of the INSTITUTE.

No programme of business having been arranged on account of the opening of the "NOVELTIES" Exhibition, the meeting was thereupon adjourned.

WILLIAM H. WAHL, *Secretary.*

[*Proceedings of the Stated Meeting, held Wednesday, October 21, 1885.*]

HALL OF THE INSTITUTE, October 21, 1885.

MR. WM. P. TATHAM, President, in the Chair.

Present—Sixty-one members.

The election of thirty-two persons to membership was reported.

The Chairman of the Committee on Science and the Arts reported the following recommendations for the award of the JOHN SCOTT Legacy Premium and Medal; viz.:

JOHN H. DOERR, WILLIAM H. WIGMORE, of Philadelphia, for their improvements in Sleeping Cars.

SAMUEL WILLS, Camden, N. J., for his improvement in Journal-bearings.

CYPRIEN CHABOT, Philadelphia, for his Straight-Needle, Waxed-Thread Sewing Machine, for Sewing Shoe Soles to Uppers.

CYPRIEN CHABOT, Philadelphia, for his Machine for Channeling Shoe Soles.

CYPRIEN CHABOT, Philadelphia, for his Sole-Edge Turning and Bending Machine.

FRED'K SIEMENS, Dresden, Saxony, for his Regenerative Gas Burner.

PAUL LA COUR, Copenhagen, Denmark, for his invention of the Phonic Wheel.

PATRICK B. DELANY, New York, for his improvements in Multiplex Telegraphy.

E. A. CALAHAN, Brooklyn, N. Y., for his improvements in Multiplex Telegraphy.

He likewise reported the following recommendations for the award of the ELLIOTT CRESSON Gold Medal of the INSTITUTE:

FRED'K SIEMENS, of Dresden, for his Regenerative Gas Burner.

PATRICK B. DELANY, New York, for his improvement in Multiplex Telegraphy.

CYPRIEN CHABOT, Philadelphia, for his Stright-Needle Waxed-Thread Sewing Machine, for Sewing Shoe Soles to Uppers.

The above recommendations were separately taken up in the order named, and were each unanimously adopted. The Secretary was directed to take the customary steps in connection with the same.

The Secretary presented his usual report of progress in Science and the Arts, whereupon the meeting was adjourned.

WM. H. WAHL, *Secretary.*

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[*Proceedings of the Stated Meeting, held Wednesday, November 18, 1885.*]

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HALL OF THE INSTITUTE, November 18, 1885.

WM. P. TATHAM, President, in the Chair.

Present—146 members and eight visitors.

The Actuary reported the election of sixty-six persons to membership; and the following preamble and resolutions, adopted at the meeting of the Board of Managers, held Wednesday, November 11, 1885, viz:

*Whereas*, Valuable service has been rendered to the FRANKLIN INSTITUTE, in conducting a series of Tests on Dynamo Electric Machines and on Incandescent Lamps, which tests were ordered by the Board of Managers; and,

*Whereas*, Said service was given without compensation, and required a large amount of labor and time;

Therefore,

*Resolved*, That the Board of Managers nominate the following named gentlemen for election to honorary membership in the INSTITUTE, for their invaluable services in conducting the electrical tests, under appointment by the President, viz.:

LOUIS DUNCAN, Ph. D., Ensign U. S. N.

JOSEPH B. MURDOCK, Lieut. U. S. N.

WILLIAM D. MARKS, Whitney Prof. of Dynamic Engineering, University of Penna.

George L. Anderson, Lieut. U. S. A., Instructor of Mathematics, U. S. Military Academy, West Point, N. Y.

A. B. Wyckoff, Lieut. U. S. N., Philadelphia.

George M. Ward, M. D., Philadelphia.

The gentlemen above named were thereupon unanimously elected as Honorary Members.

Professor E. J. Houston made some remarks on Photography by the Lightning Spark, and on the Duration of the Lightning Spark, which have been referred for publication.

Mr. H. R. Heyl, Director of the late "Novelties" Exhibition, made an oral report on the same. He stated in substance that the attendance numbered 145,000; that the cash receipts were about $43,000, and that, though it was yet too early to present a detailed financial statement, enough was known to make it safe to say, that the Exhibition had proved a financial success.

Mr. Hugo Bilgram made some remarks on the supposed Polarization of the Electric Arc Current, which are referred for publication.

On the invitation of the President, Mr. Burnet Landreth, of Philadelphia, introduced Mr. John Robinson Whitley, of London, Director-General of the American Exhibition, which it is proposed to hold in London in the year 1886. Mr. Whitley explained the character of the project above named.

The Secretary's report embraced remarks on the great extension of the use of Natural Gas in Pittsburgh and Vicinity; on the Present Prospects and Condition of the Panama Canal Enterprise; on the Phelps' System of Telegraphing to and from Railway Trains in Motion; on the Diehl Electric Motor; on the Fahnehjelm Incandescent Burner for Water Gas and similar Non-luminous Gases; and on Dr. F. V. Greene's Process of Extracting Oil from the Refuse of the Starch Manufacture, etc.

Adjourned. Wm. H. Wahl, *Secretary*.

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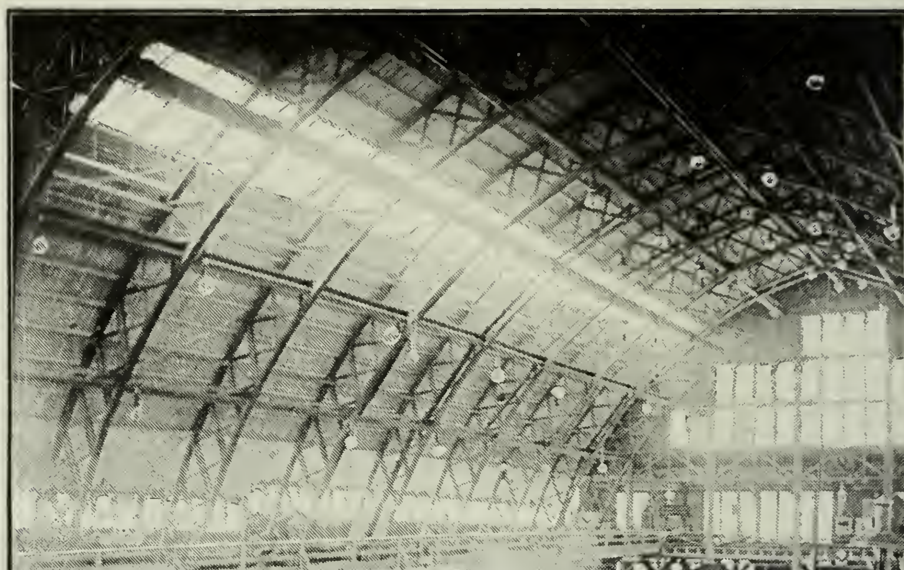
Production of Low Temperature.—Wroblewski used liquid ethylene by means of which a temperature of — 152° can be obtained. He measured the temperatures by the aid of a galvanometer and a thermo-electric couple of copper and german silver. Under the ordinary atmospheric pressure, oxygen boils at — 181·1, and nitrogen at — 193·2°. The vapor-tension of liquid nitrogen is 32 atmospheres at — 146°. Carbon monoxide boils at — 190° under the atmospheric pressure. The critical pressure of oxygen is about 50 atmospheres, and the critical temperature about — 118°. Liquid atmospheric air boils between — 187° and — 191·4° under a pressure of 740 mm., but the liquid loses nitrogen on boiling, and its boiling point gradually sinks. Under the pressure of 20 mm., oxygen boils at — 200·4°. Nitrogen boils at — 203° under a pressure of 65 mm., and solidifies to a crystalline mass. Carbon monoxide easily solidifies at — 199°. The tension of its vapor at this temperature is equal to 100 mm. As the readings of the hydrogen thermometer cease to agree with the results calculated by the aid of the galvanometer at this temperature, it is probable that hydrogen approaches its point of liquefaction at — 200°.—*Jour. Chem. Soc., July, 1885.*



THE FOUNTAIN.

1884—INTERNATIONAL ELECTRICAL EXHIBITION—1884

OF THE

FRANKLIN INSTITUTE, OF THE STATE OF PENNSYLVANIA,

FOR THE

PROMOTION OF THE MECHANIC ARTS

# GENERAL REPORT

OF THE

# CHAIRMAN

OF THE

# COMMITTEE ON EXHIBITIONS.

[ISSUED BY AUTHORITY OF THE BOARD OF MANAGERS AND PUBLISHED AS A SUPPLEMENT TO THE JOURNAL OF THE FRANKLIN INSTITUTE, JULY, 1885.]

PHILADELPHIA:
THE FRANKLIN INSTITUTE
1885.

# INTERNATIONAL ELECTRICAL EXHIBITION, 1884.

FRANKLIN INSTITUTE, Philadelphia, Pa.

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*To the Board of Managers, Franklin Institute:*

GENTLEMEN:—I have the honor to present herewith a General Report—Historical and Descriptive—of the International Electrical Exhibition.

Respectfully,

CHARLES H. BANES,

*Chairman of the Committee on Exhibitions.*

PHILADELPHIA, *March*, 1885.

# GENERAL REPORT OF THE CHAIRMAN OF THE COMMITTEE ON EXHIBITIONS.

## FORMER EXHIBITIONS.

The Franklin Institute was founded in 1824, for the purpose ot promoting the mechanic arts. It has progressively carried out the intention of its founders by means of courses of popular scientific lectures, schools for drawing, experimental tests of new inventions, by work of original research in its laboratories, and through the Committee on Science and the Arts. In addition to this, exhibitions of manufactures and processes in the arts have been given at various periods in the history of the Institute, commencing at a very early date. These displays have attracted throngs of visitors and have always been anticipated by our citizens with a great deal of interest. The last of these, prior to that of 1884, was held in 1874, and proved equally attractive as those preceding, and was in every way a successful one.

Since the close of the Centennial Exhibition in 1876, the Institute has taken no part in any display of the mechanic arts, being deterred from doing so, partly on account of the overshadowing influences of its magnitude and more especially for the reason that Philadelphia, the city noted for its skilled mechanics and extensive industries, contains no available structure that can be used for a collective exhibition representing their varied work.

## ORIGIN OF THE EXHIBITION.

The recent Electrical Exhibitions held by France, England, Germany and Austria, impressed the committee on Exhibitions with the fact that electricity, in its applications, had long since passed from the experimental period to that of permanence and practical necessity, and is to-day attracting a large share of public attention. Influenced by this thought the Chairman of the Committee on Exhibitions suggested to the Board of Managers of the Franklin Institute, at their meeting,

December 13, 1882, "That the Institute should take steps to hold an exhibition of electric lighting and of the machinery pertaining thereto." The proposition was referred to the committee, and after due consideration the following was presented to the Board, February 14, 1883:

"*Resolved*, That in the opinion of the Committee on Exhibitions it would be both practicable and advantageous for the Franklin Institute to organize an International Exhibition of Electrical Subjects, to be held in Philadelphia in the near future, and the committee so recommend."

The recommendation of the committee was approved and authority given to select a place and appoint a time for holding the exhibition.

At a meeting of the Board, held March 14, 1883, a resolution was passed enlarging the committee until it embraced all the Managers of the Institute, and subsequently the number was further increased by authority given the chairman to appoint on the committee members of the Institute who were not on the Board of Managers.

## GUARANTEE FUND.

To secure the Institute from pecuniary loss, it was deemed advisable to "raise an adequate guarantee fund to protect the interests of the Franklin Institute." A proper form was prepared for this paper and its circulation resulted in pledges from public-spirited citizens to the amount of $37,370.

## ACT OF CONGRESS.

Simultaneous with this movement, Mr. William P. Tatham, President of the Institute, addressed a communication to the Congressmen from Philadelphia, asking that steps should be taken before the adjournment of Congress to authorize the admission of foreign goods intended for the exhibition without the payment of customs duties. This request met with a prompt response and led to the passage of a joint resolution which was approved February 26, 1883. Soon after this action by Congress, Hon. Charles J. Folger, Secretary

of the Treasury, issued a circular dated March 22, 1883, giving specific instructions to the "Collectors of Customs and others" as to its interpretation. Although these instructions were in many respects similar to those heretofore issued in reference to International Exhibitions, the provisions were construed by the committee as unfavorable to the prompt admission of foreign goods. Proper representations were made to the Secretary of the Treasury, and attention called to the fact that a large part of the importations would comprise instruments not made in this country, and especially valuable for the uses of colleges and scientific institutions. This led to the issuing of a circular, dated November 14, 1883, giving more liberal and entirely different orders whereby the difficulty was removed. Under the new orders the business of receiving and entering imports was greatly facilitated, and at the same time the United States Government was amply protected. The buildings were made bonded warehouses and security was entered in the sum of $40,000 by Charles H. Banes, Dr. Persifor Frazer, and the President of the Institute.

## SITE FOR THE BUILDING.

In the progress of preparations, one of the first difficulties encountered was the selection of a proper and suitable location for the erection of a building, After considering a number of properties and encountering as many disappointments, the difficulty was met by the liberality of the Pennsylvania Railroad Company in the offer, upon nominal terms, of the lease of a vacant lot of ground belonging to that company situated between Thirty-second and Thirty-third streets, and Lancaster avenue and Foster street, Philadelphia, containing 66,645 square feet. This proposition was made through Mr. William Sellers, a member of the Board, and at the same meeting, June 13, 1883, it was unanimously accepted and arrangements made for the preparations of a lease. This was authorized to be signed December 12, 1883.

## BUILDING PLANS.

Preparations for plans of the buildings to be erected were commenced by Mr. Joseph M. Wilson, who was appointed Architect, by the Board. To increase the available space and to secure a location outside the main building for the steam boilers, authority was asked from the City Councils to occupy Foster street for the purposes of the exhibition and an ordinance was passed to this effect and approved by the Mayor. The additional space thus secured was of great advantage to the Exhibition, and at once solved the question of the proper disposition of the large amount of power required for the engines and dynamos. The plans, as submitted by the architect, were approved January 9, 1884. After proper advertisement, the contract was awarded to Jacob R. Garber, the lowest bidder, for the sum of $29,628. During the progress of the building operations, it was deemed advisable to extend the width of the north and south galleries in the main building, and to erect a large fountain to be illuminated with electric lights, and to make other changes not contemplated in the original specifications. These alterations greatly increased the cost of the structures.

To provide the necessary means for completing this work, and to meet payments promptly as they became due, the following was passed by the Board of Managers, February 29, 1884 :

"*Resolved*, That the President and Treasurer (of the Franklin Institute) be authorized to borrow the sum of forty thousand dollars, at such times and in such sums as may be found necessary to pay for the erection of the buildings and furnishing the same, and for the preliminary expenses of the proposed Electrical Exhibition to be held under the auspices of the Franklin Institute, and that for any money which may be borrowed, the President and Treasurer be, and they are hereby authorized to issue the promissory notes of the Franklin Institute, payable at such times as may be agreed upon with the lender or lenders of the money so borrowed and to secure the payment of the same by pledging as collateral security for such payment any bonds, loans, or stock owned by the Institute, and for any such pledges to make such transfers and assignments as may be required."

ADVERTISEMENTS.

The sub-committees on Space and on Publication, commenced active work in January, 1884. "Rules and Regulations," "Application for Space" and "Information for Exhibitors," were prepared and printed in English, German, French and Italian and were mailed to parties interested in electrical matters in the United States and foreign countries. The subject was also brought directly to the attention of foreign governments through the courtesy of Hon. F. T. Frelinghuysen, Secretary of State of the United States.

To give further publicity to the exhibition, and especially to inform the general public of the progress of preparations and awaken interest in electrical matters, a semi-monthly paper, edited by the Chairman of the Exhibition Committee, aided by his associates, was published on the 1st and 15th of each month, commencing June 2, 1884, and continuing until the close of the exhibition. Files of this Journal, the "Bulletin of the International Electrical Exhibition," preserved in the Library of the Institute, furnish a record of value as a narration of the progress of the work of the committees, together with many papers of value and merit, written by specialists, upon electricity, magnetism, and collateral subjects. The circulation of the "Bulletin" amounted to over 2,000 copies for each edition, and these were distributed free to colleges, libraries and scientists in various localities throughout the United States and Canada. The paper became very popular and copies were sought after by persons from all sections.

In addition to the publicity given to the exhibition by means of the distribution of official printed matter, a comprehensive scheme for advertising was devised by the Committee on Correspondence and Publication, and through a special committee, of which G. Morgan Eldridge and Jules Viennot were exceedingly active members. In the execution of this plan, lithographs of the buildings were through the courtesy of the railroad officials, placed in every important depot and station on the Pennsylvania and the Reading railroads, and their connections. Thousands of these lithographs were also distributed by the

merchants of Philadelphia, through their correspondents. Printed circulars and programmes were mailed to large numbers of newspapers and private schools, and also placed in prominent hotels at summer resorts. Large posters, containing a picture of the buildings and annex, with date of opening of the exhibition, were displayed in conspicuous places in towns in Pensylvania, and the northern and western states. There was also a large amount of advertising done in many prominent daily papers and scientific journals. The work of this committee was very effective, marked by great enterprise, and beyond doubt added largely to the receipts from visitors. In this connection it is proper to acknowledge the invaluable assistance that was rendered by all the daily newspapers of our city, and scientific journals of this and other cities, especially the New York "Electrical World," the "Electrical Review," "The Electrician," and the "Scientific American," in frequent gratuitous notices of the progress and development of the exhibition. The "Philadelphia Record," devoted a large part of two editions to the exhibition, publishing a full page illustration of the building without cost to the Institute. The Philadelphia papers furnished without charge, copies of their daily issues to the reading room at the building. The

GENERAL CLASSIFICATION OF THE EXHIBITS,

and the synopsis of the same, was prepared by a sub-committee of which Prof. Pliny E. Chase, of Haverford College, was chairman. Especial attention is called to the work of this committee, on account of the labor performed and the fidelity with which it discharged a duty requiring much thought and study as well as familiarity with the productions and applications of electricity. The work has been highly commended by scientists and experts, and is in itself a complete index of electrical progress, as recorded in the literature of the subject at at the date of the exhibition.

## SUPERINTENDENT AND ELECTRICIAN.

In April, 1884, Prof. William D. Marks, of the University of Pennsylvania, accepted the position of General Superintendent, and Prof. Edwin J. Houston, of the Central High School, Philadelphia, that of Electrician. These gentlemen brought to the duties of their positions that energy, enthusiasm and special fitness that tended so largely to the success of the exhibition. They were untiring in their efforts, and under circumstances of unusual difficulty commanded the respect of those with whom they came in contact.

For the purpose of securing the highest possible safety, both to life and property, a Committee for the Installation of Electrical Apparatus was appointed, consisting of Prof. Edwin J. Houston, Chairman, Henry Morton, Charles M. Cresson, M. D., W. P. Tatham and M. B. Snyder. A code of carefully prepared rules was adopted, and exhibitors were requested to give their co-operation in carrying them into effect.

These rules were carried into effect under the able personal direction of the Electrician, Prof. Edwin J. Houston. Their actual application demanded constant and untiring attention on the part of the Electrician and his assistants, so as to meet the requirements of particular cases as they arose. Not only electrical skill, but practical knowledge was required in order to safely conduct through a frame building the intricate net work of wires to supply the various exhibits. The able manner in which this was accomplished even in its minutest details, is witnessed by the fact that although many of the arc light circuits had an electro-motive force of as high as 3,000 or 3,500 volts, no single accident to life, or alarm of fire, occurred in the buildings during the entire period of the exhibition.

The circuits were tested daily for " contacts " or " grounds " by Prof. Houston, or by his assistant Mr. Carl Hering, and all causes of danger removed before the current was permitted in them.

Mr. Hering, the assistant electrician, rendered valuable and able services not only to the Electrician in aiding the testing and the location of the various circuits in the building, but also to the committees

appointed by the Institute for making tests and measurements. He was specially fitted for these duties by his laboratory experience and the information acquired during the Vienna Electrical Exhibition of 1883, where he officially represented the Franklin Institute. The

ARRANGEMENTS FOR THE EXTINGUISHMENT OF FIRES

were very complete and worthy of notice. The fire patrol consisted of men from the Philadelphia Fire Department, assigned by authority of the Fire Commissioners and under the personal direction and control of Chief John R. Cantlin. These firemen were selected for their experience and fitness, and a detail was on duty continually, day and night. "The committee to procure appliances for the extinguishment of fire," was composed of Captain McDevitt, C. J. Hexamer, and William B. Cooper, aided by the counsel of Captain Stillman, of the Insurance Patrol. The principal reliance, in case of fire, was upon a chemical engine, loaned by Messrs. W. K. Platt & Co., of Philadelphia, and hand fire extinguishers.

The efficiency of the preparations was fully tested by the promptness with which the detail extinguished a fire that took place at midnight in the car sheds of the railroad adjoining the annex. This latter occurrence illustrates the dangers that may sometimes threaten electrical exhibitions located in proximity to railroad stations.

THE DETECTIVE AND POLICE FORCES

were well managed. The former was under the charge of Chief Samuel I. Givin, who was constantly on duty, and it is to his credit to state that there was entire freedom from robberies or the operations of pickpockets. The daily details of patrolmen from the city police force, to assist in preserving order, were kindly furnished by his Honor, William B. Smith, Mayor of Philadelphia, and the Institute is under obligations for the promptness and efficiency with which their services were rendered.

## OPENING CEREMONIES.

The exhibition was opened at the time indicated in the advertisements, September 2, 1884. The ceremonies began in the building lately used as the station of the Pennsylvania Railroad, loaned to the Institute, and used as the Annex. It was connected with the main buildings by means of a bridge over Thirty-second street, and reached by a broad flight of stairs, leading from the north avenue of the station. The large waiting room had been extensively repaired and placed in complete order, a lecture platform and large screen for illustrations erected at the north end, and two special apartments set aside in the southern portion for historical and bibliographical displays. The recently bare walls were rendered attractive with very large maps of the hemispheres, upon which were shown the locations of the sub-marine cables and of the principal overland wires. These were executed in distemper by a prominent scenic artist of Philadelphia from designs collated by Prof. Houston. Above the Market street entrance, the wall was decorated with red, white and blue bunting. The front and sides of the platform were completely hidden from the audience by growing plants. The space above the rear of the platform was tastefully decorated with the national colors.

The invited guests, among whom were representatives of foreign governments, scientists and many distinguished citizens assembled in the lecture hall at noon. After an overture by the Germania Orchestra, Hon. George H. Boker, Chairman of the Committee on Ceremonies, introduced His Honor, Mayor Smith, who welcomed the guests to Philadelphia. The procession was then formed and moved across the bridge to the main building where thousands of people had already assembled. After prayer, by Rev. Dr. J. S. McIntosh, William P. Tatham, President of the Institute, delivered the opening address, and at its conclusion, introduced Governor Robert E. Pattison, who in well chosen words declared the exhibition open. At the touch of an electric button by the wife of Prof. Marks, the Superintendent, the

machinery started and electric lights flashed in every part of the large structure. The opening scene was one of great attraction and brilliancy.

## COLLEGES AND SCHOOLS.

The preparations for the exhibition entailed a large amount of labor and responsibility upon the committees, occupying a period of several months, and this work by no means terminated at the day of opening. Impressed with the fact that foreign electrical exhibitions had been attended with pecuniary loss to the projectors, the committee determined to awaken a special interest in the colleges and schools of the country, for the purpose of inducing a large attendance of scholars as visitors. Nor was this motive entirely mercenary, for it became evident early in the preparations, that the educational facilities would be unsurpassed and ought not to be neglected. With this view, Mr. G. Morgan Eldridge, Chairman of sub-committee on schools, addressed communications to a large number of schools throughout the country, announcing the character and peculiar attractions of the exhibition, the arrangements made for transportation, and the reduced price of admission for schools visiting in a body. In response to a proposition made to the Board of Education of Philadelphia, the public schools of the city of the grade of high, normal, grammar, and unclassified, were granted each one day of vacation during the school term to attend the display. As the result of these arrangements, the official record of admissions, shows an attendance, as organizations, of 97 schools, with 740 teachers and 16,657 students. In addition to these formal visits, there was an attendance at different periods of a number of sections and single classes.

To facilitate the work of teachers in making the visits profitable to their pupils, arrangements were effected with professional men, familiar with electrical matters, to act as guides in explaining the uses of the machines, and the theories of electricity to the young visitors and without cost to them. This scheme proved of great value as a series of interesting object lessons.

A special inducement for study and observation of exhibits was

offered the scholars of the public schools in the offer of prizes, consisting of a five dollar gold piece, and an honorable certificate of the Franklin Institute for the best compositions upon the subject, "What I saw at the Electrical Exhibition." The number of prizes distributed amounted to eighty, of which sixteen were secured by the High and Normal schools, and the remainder by the Grammar and Unclassified schools. In addition to these awards, two special prizes of ten and fifteen dollars were added by the "Electrical World," of New York. These were distributed, with appropriate ceremonies, before a large audience assembled at the Normal School building, Thanksgiving night, Nov. 27, 1884.

The preparation for the plans to enlist the interest of the public schools and the laborious details incidental to the distribution of tickets, and the collection of the payment for the same, was voluntarily undertaken by Prof. James MacAllister, Superintendent of Public Schools, in Philadelphia. In addition to this work he also placed the committee under great obligations by his arrangements for, and personal attention to the selection of the prize compositions. In the discharge of this last duty Prof. MacAllister was ably assisted by Prof. Vogdes, of the High School, and by the Secretary of the Institute.

## LECTURES.

To add still further to the educational attractions, arrangements were made for an excellent course of lectures, under the care of a committee appointed for the purpose. The report of the Chairman is annexed and will be found of interest, as illustrative of the high character of the lecturers in their various specialties. For the public schools, a special course upon electrical subjects was delivered by Prof. Houston. The school lectures were profusely illustrated and although necessarily elementary were exceedingly interesting and profitable. Two were given each day during the visits of the schools, covering a period of three weeks, and the close attention of large audiences was held during the time of delivery. Prof. Houston was greatly assisted in this work

by the liberality of Jas. W. Queen & Co. in furnishing, as a loan, a large variety of apparatus under the care of trained assistants. Valuable aid was also given in the illustration of electric currents by the Edison Co. This latter service required the special work of their large dynamo. Numerous testimonials to the value and usefulness of Prof. Houston's course have been received.

### MUSIC.

To popularize the exhibition to those visitors who might not be attracted by a display confined entirely to a special science, and who desired amusement as well as instruction, concerts were given every afternoon and evening. The music was furnished by the Germania Orchestra, led by Prof. Charles M. Schmitz. In addition to this, organ recitals were given at stated periods, upon an organ operated from key boards, placed at a distance, by means of an electric action. The movement for the bellows was furnished by an Edison motor attached beneath. This instrument was loaned by H. L. Roosevelt, of New York, and was formerly in the New York Academy of Music.

### FOUNTAIN.

Another important feature of popular attraction was the large fountain occupying the middle portion of the main building. From the flower banked borders of the basin, thirty feet in diameter, there issued twelve jets of water, the curved trajectory of the streams dashing in spray against a truncated cone of rock-work in the centre of the basin. From the apex of the cone there flowed a dome-shaped sheet and a convolvulus jet of water. To make an economical use of the large quantity of water required to continually supply these jets and streams, the basin was first filled, and afterward the same water was used over again for weeks without calling upon the service pipes of the city. This was successfully accomplished by the use of two steam pumps, capable of forcing 3,000,000 gallons per day, loaned by the Worthington Co. The beauty of this attraction was greatly enhanced

at night by electric illumination and prismatic changes of colors. To heighten the effect, the lights were extinguished in the great arch of 100 feet span, and the fountain presented a picture of marvellous beauty, first as flowing fire of different colors, then in the bright white of dazzling silver, quickly turning to softer rays with each change of the prism. The periods of illumination were announced by programmes and never failed to attract enthusiastic spectators. Numbers of people repeatedly visited the exhibition to witness this wonderful feature. The plan and construction of the fountain was under the personal superintendence of Prof. W. D. Marks, to whose good taste and energy the result was a fitting tribute.

### PRIMERS OF ELECTRICITY.

To enable visitors to properly understand the names and uses of the machines and instruments on exhibition, a large number of placards and descriptive signs were placed about the building and attached to exhibits, giving in popular phrases their name and a brief description. In addition to this information a series of elementary papers called "Primers of Electricity," were written by Prof. E. J. Houston. These were printed on four and eight pages, illustrated, and were sold at a nominal price. Over eighty thousand were disposed of, and they became very popular and useful to visitors and young students. Notwithstanding the low price at which they were sold, they proved a source of considerable revenue to the Institute.

### STEAM-POWER AND ENGINES.

At a very early period, in the preparations by the committee, the question of steam-power and engines to drive the dynamos demanded the serious consideration of the sub-committee having this matter in charge. Mr. Frederick Graff, a most efficient chairman, aided by Messrs. Washington Jones, Henry C. Davis, W. Barnet Le Van, and others, bestowed not only a great amount of labor in planning the work, but cheerfully gave valuable time in arranging with manu-

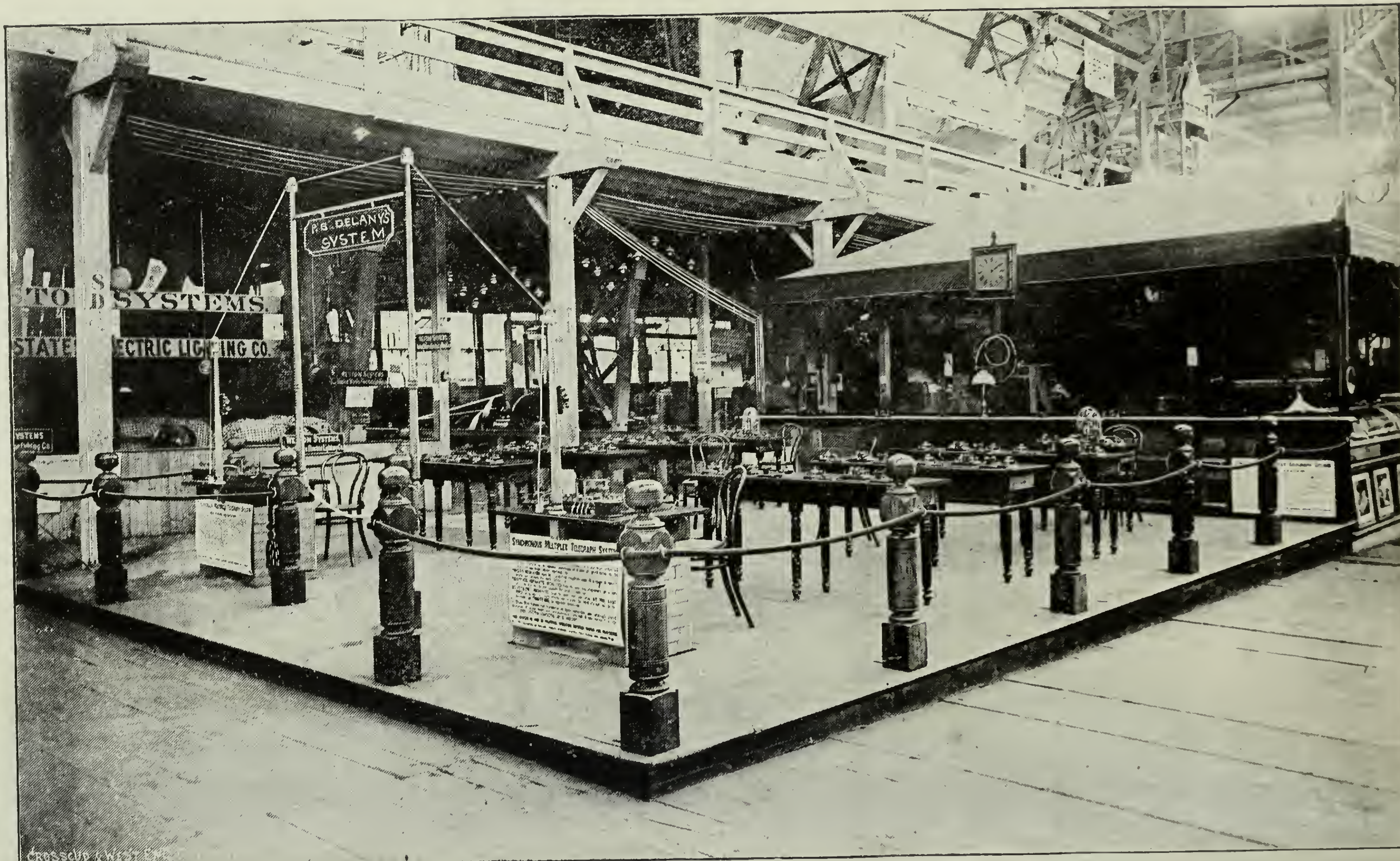



EXHIBIT OF DELANY'S SYNCHRONOUS MULTIPLEX TELEGRAPH SYSTEM.

facturers to take part in the exhibit. From the time of opening until the close of the exhibition the boiler-house constructed of wood, with a corrugated iron roof, and occupying the entire length of Foster street, from Thirty-second to Thirty-third streets, was a place of great interest and was visited by a large number of people. Arrangements were made and successfully carried out, whereby visitors could examine any boiler in operation without being incommoded, as is often the case in similar exhibitions, by the annoyance of ashes, dust and leaky joints. The entire building devoted to the generation of steam was well arranged and ventilated, and with good lighting facilities. The total amount of 1,800 horse-power was furnished by four Babcock & Wilcox boilers, three Harrison, one Burnham, Parry, Williams & Co. (steel), two Abendroth & Root, one Dickson & Co., Scranton, Pa., and four locomotive boilers, two of these latter being furnished each by the Pennsylvania Railroad and Reading Company. With the exception of two of the Babcock & Wilcox, these boilers were loaned for use without charge, the exhibition furnishing fuel and expense of firing. The steam pumps supplying these boilers were loaned for use by Davidson Steam Pump Company, New York, and others.

Exhibitors were furnished with power, either from shafting driven by engines under the control of the committee, or steam was supplied directly to engines installed as part of individual or company exhibits. Among the former were those of the Southwark Foundry and Machine Co., Buckeye Co., Salem, Ohio; Kensington Engine Works, Philadelphia; Straight-Line Engine Co., Syracuse, N. Y., and New York Safety Steam Power Co. Some of these firms with others, mentioned in full in the catalogue and reports, supplied individual exhibits with power direct. With the collection of boilers and engines were many new and valuable appliances for the generation and economical use of steam. For a complete list reference can be had to the report of the Committee on Tests of Boilers and Engines. Without desiring to do injustice to other members of this special committee it is but proper to mention the intelligent and faithful work done by Mr. H. W.

Spangler, in charge of boiler and engine tests, and the able assistance rendered by Mr. Arthur L. Church, Superintendent of Power.

### LOCATION OF EXHIBITS.

The sub-committee on space had many difficult problems to solve, and was without the experience gained by precedents, this being the first exhibition of strictly electrical matters held in this country. To do justice to the exhibitors, required the close personal attention of the chairman of this committee, Mr. Charles Bullock, who for several months preceding and during the exhibition neglected his private business in order that he might discharge the duty of locating exhibits. In spite of complex questions, arising from the novelty of the demands, the committee gave very general satisfaction. The charges for space and the rules governing the use of the same are contained in the annexed "rules and regulations."

### DEPARTMENT OF ADMISSIONS.

The Department of Admissions was under the charge of Mr. Samuel Sartain, Treasurer, and Mr. Henry R. Heyl. The system devised and put in operation could scarcely be improved upon. The sub-committee consisted of Samuel Sartain, Henry R. Heyl, Dr. Isaac Norris, Jr., and William H. Wahl, and from their full and interesting report of detail on file in the Institute, the following extracts are made: "The price of admission was fixed at fifty cents for adults, children twenty-five cents, for pupils of the public schools of Philadelphia visiting by sections, fifteen cents, and for all other schools coming in a body, twenty-five cents. Teachers accompanying pupils of Philadelphia public schools were admitted free, and likewise one teacher with every fifteen pupils of other schools. During the third week of the exhibition the committee issued a special ticket for thirty-five cents, for sale in large quantities, to societies and industrial establishments. At the same time a form of ticket was issued containing ten coupons for three dollars and fifty cents. These were not good except detached by the turn-

stile keepers. The total number of admissions was 282,779. The cash sales of tickets amounted to $98,639.70. In addition to the schools, visiting in a body, there was a large number of other organizations, industrial and scientific, that attended the exhibition during its progress. Among the latter were the United States Electrical Conference, the American Association for Advancement of Science, the British Association for the Advancement of Science, the Royal Society of Canada, the American Institute of Electrical Engineers, the American Institute of Mining Engineers, the New York Electrical Society, the Agassiz Association, the Inter-Collegiate Association of Alumnae, and others. The committee acknowledge the courtesy of Messrs. Farrel & Co., who loaned without charge two commodious fire-proof safes, and Messrs. Westcott & Thomson, who donated all the electrotype plates for the production of tickets."

The number of visitors to the exhibition was largely increased by the enterprise of the Committee on Advertisement in their arrangements for excursions from towns in the interior. By this means, reduced railroad rates were secured and an interest awakened to the advantages presented. Several of these excursions came from towns over one hundred miles from Philadelphia, returning the same day to their homes.

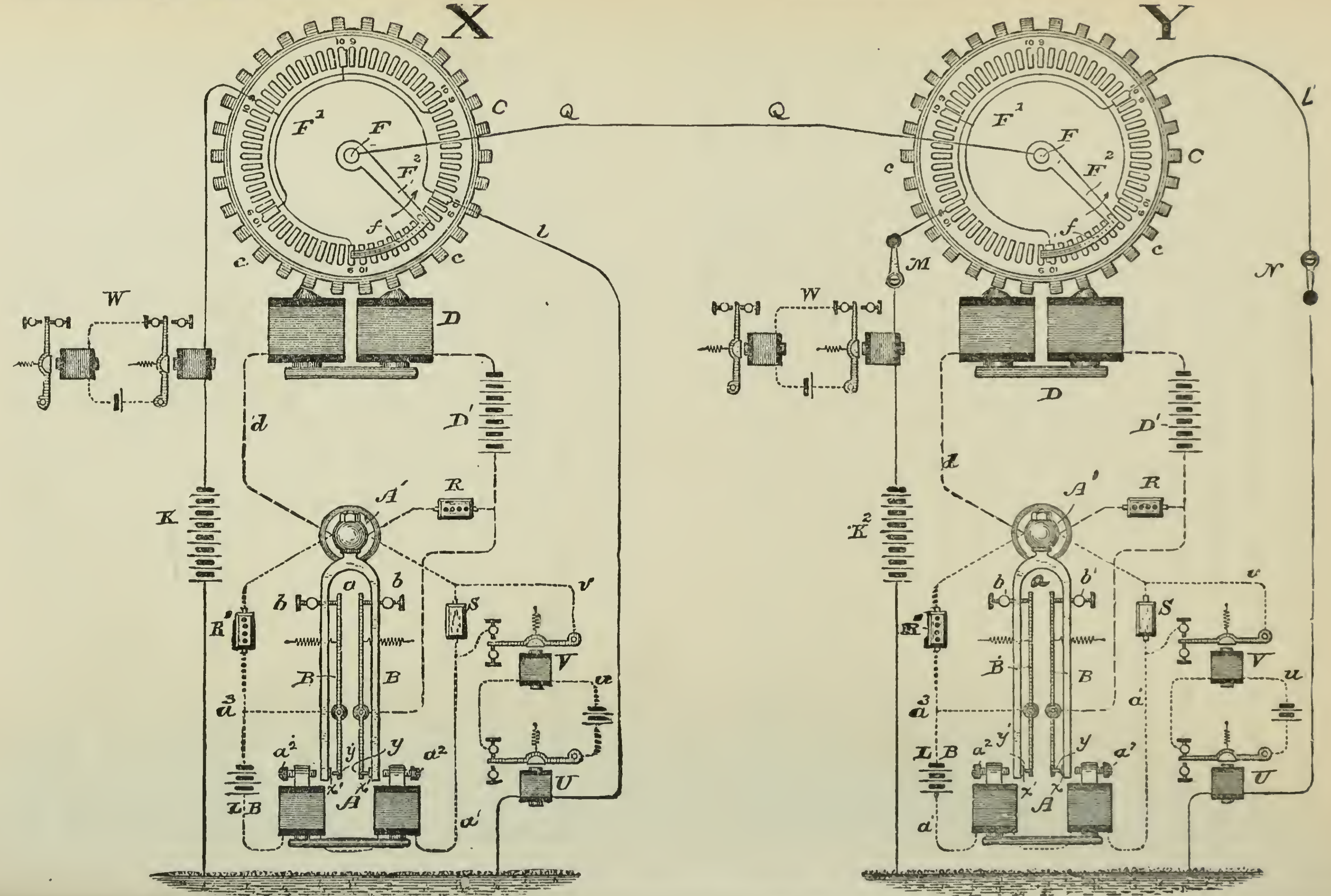
### COMMITTEE ON BIBLIOGRAPHY.

The report of the Committee on Bibliography, charged with the special duty of preparing a collection of books and pamphlets relating to the subject of electricity and magnetism, shows as the result of their work a memorial library, consisting of volumes, bound and unbound, monographs and pamphlets, numbering 2,976. There was also contributed about one thousand dollars in cash. In soliciting the co-operation of English and Continental book publishers, the committee was favored with the valuable assistance of Mr. Frederick Ransome, member of Institute, residing in London, and Mr. Coleman Sellers, at the time in England, and a representative of the Franklin Institute, by invitation, to the ter-centenary of University of Edinburgh, and Mr. Leopold

Bossange, of Paris. This library, in accordance with the proposition contained in the invitation to doners, was formally presented to the Franklin Institute at the close of the exhibition. It will be preserved and increased as new books may be secured and will prove of great value for reference and study. The catalogues of books and subjects is well worthy of examination and was prepared with a great deal of care by Mr. E. Hiltebrand, Librarian. Dr. Isaac Norris, Jr., and his colleagues of the committee, Messrs. Wahl, Houston and De Motte, were indefatigable in pushing the work to the success it attained. In this connection it is proper to acknowledge the valuable services voluntarily rendered, not only as a member of this committee, but in other departments, especially that of lectures and historical display, by Prof. John B. De Motte, of DuPauw University, Greencastle, Indiana. The trustees of this institution kindly extended a leave of absence for several months to the Professor so that he might assist in the work of the Institute.

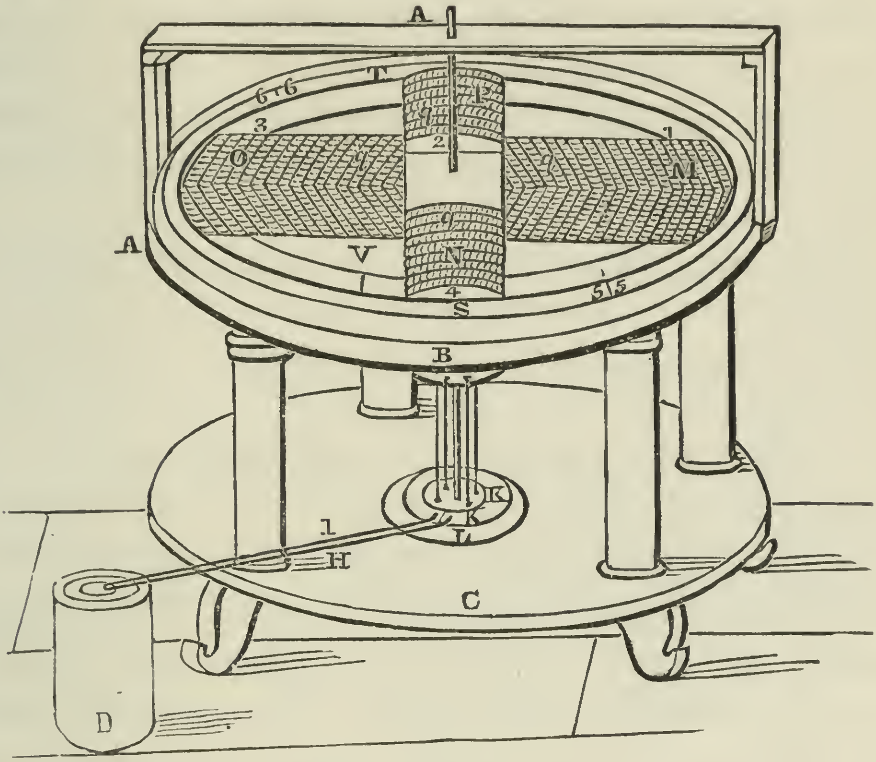
## SPECIAL HISTORICAL EXHIBIT.

In order that the progress of electrical science might be traced from its earliest history, by visitors and students, it was deemed advisable to prepare a special historical exhibit. In the rooms set apart for this purpose many valuable machines and models, loaned in response to requests of the committee, were arranged, and attracted a great deal of attention. The historical report will present a list containing almost every invention of value in marking the development of electrical science. The most conspicuous, in extent was the exhibit of the United States Patent Office. Over two hundred models, many of them of rare interest, were arranged on tables and so labeled as to clearly indicate their title and purpose. A complete list appears in the catalogue, and the committee appreciate the kindness of the Commissioner of Patents, and Mr. C. J. Kintner examiner in electricity, manifested in the loan and preparation of this display. Many individuals and firms added interest to the collection by sending machines of value. Prominent




THE DELANEY SYNCHRONOUS-MULTIPLEX TELEGRAPHY.

among the latter was the exhibition of Messrs. Wallace & Sons, Ansonia, Conn., this firm forwarded nine machines, among them the magneto-electric telemachon, for the development of power at a distance from its source. This was used at the Centennial in 1876. In order that the Wallace machines could be supplied with power, they were assigned a special location in the main building. The Franklin Institute added to the interest of the collection by depositing some of the original Franklin apparatus.




Davenport's Electric Motor. (From Exhibit of U. S. Patent Office.)
Patented February 25, 1837.

No portion of the vast collection in the electrical exhibition afforded greater interest for the thoughtful than the historical display. So great has been the progress in improvement since the House telegraph patent of 1846, the electric light patents of 1861, and the telephone patents of a still later date, that the famous first message of Prof. Morse has become a fitting legend for electrical progress, "What hath God wrought!"

## GOVERNMENT EXHIBITS.

From the beginning of the work the exhibition Committee had the cordial co-operation of the Executive and the heads of Departments of the Government. These efforts were restricted, however, by the want of funds. Congress, while appropriating large sums of money to exhibitions at New Orleans and other cities, did not see fit to assist the Philadelphia exhibition except by resolutions. This failure rendered it necessary for the Franklin Institute to bear the expense incidental to the transportation and installing of Government exhibits, and no money was spared to have the display made in a creditable manner. The following Departments were represented by interesting collections:

Ordnance Department, U. S. Army, in charge of Captain O. E. Michaelis.

Ordnance Department, U. S. Navy, in charge of Lieutenant Bradley A. Fiske.

U. S. Coast and Geodetic Survey, Treasury Department.

Smithsonian Institution.

U. S. Signal Office; in charge of Sergeant A. Eccard.

These exhibits embraced instruments of precision as well as electrical apparatus. An attractive feature in the contributions of the U. S. Navy was a search light of great power. This was mounted upon the north-east tower of the main building, and at night proved an object of great interest and wonder as its powerful rays of light illumined distant parts of the city. The thanks of the committee are due to the heads of Departments, and to the officers in charge for their efficient aid.

## LIGHTING THE BUILDING AND GROUNDS.

The electric lights in the buildings were furnished proportionately, and without charge by all companies having dynamos on exhibition. The main arch and galleries were illumined by arc lights and the other portions of the main building by incandescent lamps. The lecture

room in the annex was exceedingly well lighted by the tasteful chandeliers of the Edison Company, the current being furnished by their large dynamo, popularly known as "Jumbo." The restaurant adjoining the lecture hall was lighted without cost to the exhibition by the Siemens Regenerative Gas Company. This latter arrangement was entered into for the purpose of affording the public an opportunity to compare the methods of illuminating. The light furnished by the Siemens Company was quite satisfactory, and at the same time their process of combustion assisted materially in keeping the room ventilated.

Outside the buildings and fixed with brackets to the side of the structure there was a cordon of arc lights of the Brush Electric Company of Cleveland. The grounds about the buildings and annex, were lighted in like manner by the Thomson-Houston Company. To accommodate visitors arriving and departing by the Powelton avenue station of the Pennsylvania railroad, located three squares from the exhibition, the Van De Poele Company of Chicago run a series of arc lights along the sidewalks the entire distance. In addition to this exterior lighting, for practical uses, the brilliancy of the scene was still further enhanced by the display of lights from the towers by the companies named, and also by a large collection of Edison white and colored incandescent lamps, forming a star of dazzling beauty, and seen at a long distance from its location on the southeast tower.

## UNITED STATES ELECTRICAL CONFERENCE.

Prominent among the list of scientific associations that visited the exhibition was the United States Electrical Conference. In May, 1884, an act of Congress was approved by the President, authorizing the appointment of a scientific Commission "which may in the name of the United States Government conduct a national conference of electricians in Philadelphia in the autumn of 1884." By virtue of this bill the "United States Electrical Commission" was created for the purposes set forth. Professors Henry A. Rowland, George F.

Barker, Simon Newcomb, C. F. Brackett, J. Willard Gibbs, John Trowbridge, F. C. Van Dyck, Charles A. Young, M. B. Snyder, E. diven J. Houston, Dr. W. H. Wahl and Mr. R. A. Fisk, comprising the board, issued invitations to a large number of scientific gentlemen, both foreign and American, to assemble in conference. There was a large number of acceptances, and the meetings were held in September, first in the lecture hall of the exhibition, and afterward at the building of the Franklin Institute. A perusal of the report of papers read and the discussions consequent thereon confirms the statement of the preamble to the bill creating the Commission that "The International Electrical Exhibition offers a rare and fitting opportunity for such an official assemblage of electricians." The members of this Commission manifested a cordial desire for the success of the exhibition, and the endeavor to gather from the display the fruits of scientific tests and examinations.

### COMMITTEE ON MEASUREMENTS AND TESTS.

In addition to their work in the conference, Professors Brackett, Young, Van Dyke, Trowbridge, Anthony and others, spent days of valuable time rendering important voluntary assistance as members of the Committee on Measurements and Tests. The last-named committee was appointed by the Board of Managers of the Franklin Institute, and was an independent body working without the direction or control of the Committee on Exhibitions. The Chairman, Prof. M. B. Snyder, of the Central High School of Philadelphia, succeeded in obtaining the services of a number of the most prominent scientific men in the country to act as examiners in this and other work connected with the exhibition. The results of examinations by this board of examiners will be the subject of special reports to the Institute, and are now being published as fast as completed.

For the purpose of affording needed facilities for investigation, especially in delicate tests and measurements, a frame structure was erected upon a lot of ground on Lancaster avenue, west of Thirty-

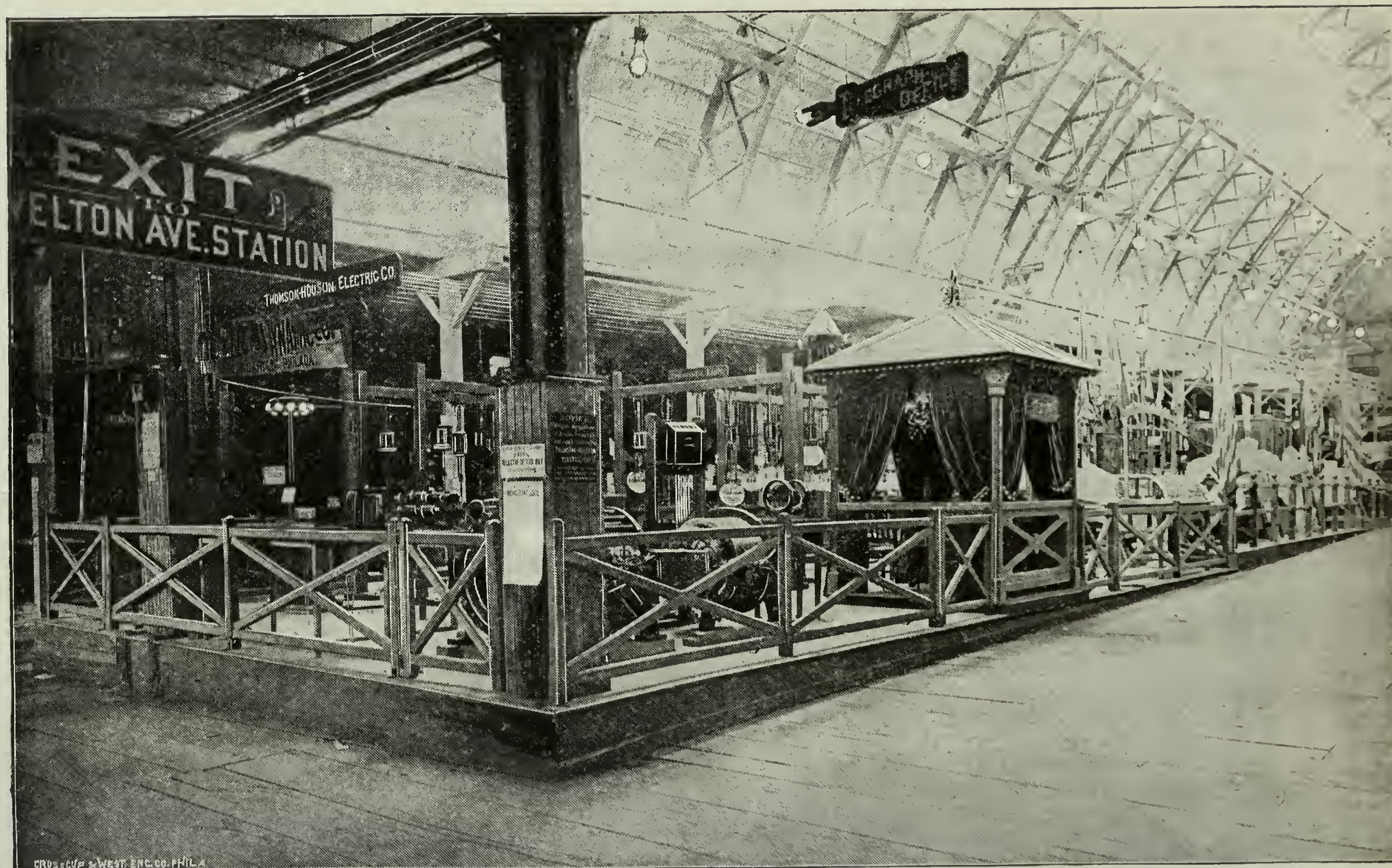



EXHIBIT OF THE THOMSON-HOUSTON ELECTRIC COMPANY.

third street loaned by the Pennsylvania railroad. Within this building a photometric room was constructed, and piers built for the installation of instruments of precision. Upon the grounds adjacent, a large number of telegraph poles were erected, and wires placed thereon, with frequent loops to obtain length of circuit and to form a rheostat. In this latter service material aid was rendered by the efficient Chief of the Electrical Department of the City of Philadelphia, David R. Walker. The committee are indebted to Mr. Walker for many facilities and services afforded by his department.

## SOME OF THE EXHIBITS.

The official catalogue, furnished with commendable promptness by Burk & McFetridge, gives a full list of exhibits and renders further details unnecessary. There are, however, some features of the display that deserve special mention, on account of their extent and character. The Edison exhibit, representing the six companies of the combination, occupied several large spaces, and the great variety of instruments, appliances and machines were arranged with attractiveness. The incandescent system was shown completely organized as from a central lighting station. The extreme beauty of their lamp clusters and electroliers was illustrated in their own space, also in the offices of the exhibition, lighted by this Company, and in several well-furnished rooms and private exhibits. A prominent feature, and one that attracted a great deal of attention, was a pyramid thirty feet high, and six feet at base, containing twelve hundred incandescent lamps. At regular hours it was illumined, and was the centre of great interest to visitors. Their large incandescent dynamo invited especial attention.

The United States Company exhibited both arc and incandescent lighting. It occupied a large amount of space, and the display was exceedingly creditable in materials and in artistic arrangement. Several of the electroliers were of remarkable beauty.

No Company presented a more systematic display of electric lighting machines and accessories than the Thomson-Houston Company,

and it was particularly valuable from an educational point of view. The exhibit had been carefully set up in Lynn before it was brought to Philadelphia, and throughout gave evidence of the conception of a perfect organiser. Some of the instruments, with mechanism dissected, illustrating the principles involved in working their machinery, and the large solenoid, showing curious magnetic effects were the source of continued study especially by amateurs. The thoughtful courtesy of Mr. Peck in working the projecting lantern for the fountain, places the committee under obligations to him.

The Brush exhibit is well described in the Catalogue. The furnished interiors, drawing-room, bed-room, office and mill-room were well arranged to illustrate interior illumination, and were lighted by the Swan incandescent lamps run by Brush low tension dynamos. The storage or secondary batteries shown in operation attracted universal attention.

The display made by Edward Weston, Newark, N. J., was a notable one in extent, and remarkable for the good taste displayed in conjunction with much apparatus of a highly scientific character.

Show-cases filled with exquisite electro-plates of natural objects, as ferns, leaves, flowers and golden rod, and with perfect reproduction of the greatest triumphs of Japanese and classic art-metal-work, gave a handsome and perfect illustration of electro metallurgy.

The display of Mr. Weston also embraced machines and apparatus used in the manufacture of incandescent lamps. The visitor was shown the method of forming the carbon from the gun cotton to the finished filament of tamidine ready for the treatment of a skilled workwoman. The exhausting processes, by means of the Geissler and Sprengel pumps, were also shown. The exhibits were placed under a canopied area which contained a rare display of the scientific instruments required in actual practice. These instruments were for the most part made by or under the personal direction of Mr. Weston, and evidenced most thorough and careful workmanship. The study of their mechanism afforded much satisfaction to electricians.

Great admiration was evinced by visitors for a mimic waterfall for

which the water was pumped by electrical motors. The ingenious arrangement of cork bark to simulate rocks, and the exquisite taste displayed in the arrangement of flowers, was due to Mr. Alex. P. Wright in charge of this exhibit. His constant affability as well as that of his assistants added much to the pleasure of many of the visitors.

Not only on account of his world-wide reputation, but also for the evident interest he manifested in the exhibition, the display of the productions of Thos. A. Edison was a prominent feature. Mr. Edison gave personal supervision to the arrangement of details, and the description in the catalogue affords a study of electrical matters that seems marvelous. The "speaking phonograph," "musical telephone," "motophone," "chemical recording telegraph," "electric motograph," are but a few of the wonderful and complex machines spread out for curious eyes to examine.

In addition to the larger display of the electric light companies, the Van De Poele, Ball, Bernstein, Excelsior, McTighe, Union Switch and Signal Co. and others, gave handsome illustrations of their systems.

The most prominent exhibit by telephone companies was made by the American Bell Co. conjointly with the Western Electric Co. A telephone exchange system was established connecting some twenty-five exhibitors with the offices of the Exhibition, and the subscribers of the Philadelphia Exchange. The Exhibit was an interesting display of a large variety of telephones from the first invention to the more recent patents. Somewhat less conspicuous than others, but exceedingly valuable and suggestive, was the contribution of Professor Amos E. Dolbear, of Boston. His original magneto-telephone and his system of electrostatic telephones, transmitters and receivers have a valuable reputation for work and ingenuity well known to experts, and their effect in operation was continually tested by electricians.

The private exhibits of Prof. Asa Gray, occupying a large space in the main hall, was a very important one, illustrating the wonderful inventions of a man known throughout the country as a pioneer in electrical work. The Professor manifested great interest in the exhibi-

tion by the care and labor bestowed in collecting and forwarding this attractive showing of the life-work of a master. A leading feature of the display was the Harmonic system of telegraphy. By a most unfortunate accident all mention of Gray's exhibit is omitted in the catalogue.

By a singular coincidence, on the side of the main hall directly opposite to the exhibit of Mr. Gray, of his Multiplex Harmonic method, was the most recent advances of Mr. Delany in Synchronous Multiplex Telegraphy. This was an interesting exhibit from the novel character of the results obtained. By means of this system, as many as seventy-two separate and distinct telegraphic messages can be sent over a single telegraphic wire, either all in the same direction, or any part of the entire number in one direction, and the remainder in the opposite direction. This exhibit attracted the liveliest attention both from practical electricians and from scientific men. From the former on account of the great advance in the actual operations of telegraphy effected by the use of the system, and from the latter because Mr. Delany has obtained in the use of his system a synchronism more absolute than ever before thought possible.

## FOREIGN EXHIBITORS.

The large majority of foreign exhibitors availed themselves of the advantages to be derived from the agency of American firms. The Electrical Supply Co., of New York, Theodore Mace, Agent, and Jas. W. Queen & Co., Philadelphia, in addition to their own manufactures and importations, represented about forty different makers. Some of the consignments of the latter firm passed the Custom House at so late a period that there was but little time for proper examination. As the invoices covered goods of great value, and represented the more recent inventions of prominent firms, it has been deemed advisable for general information to append a brief description of some of the most important apparatus and instruments.

The display made by James W. Queen & Co. was of great value to the

Exhibition, especially from a scientific and educational point of view, as they had with promptness and energy collected and arranged one of the largest and most complete collections of apparatus for electrical measurements and educational purposes ever exhibited in this country, representing many of the most celebrated makers of physical instruments in Europe. The efforts of Queen & Co. to induce foreigners to exhibit met with an amount of success which was of great importance to the International character of the Exhibition. By means of these efforts the Exhibition was fortunate in securing complete exhibits of the well-known apparatus of Carpentier, Breguet, Edelmann, Hartmann, Verdin and the Société Génevoise.

The Queen & Co. exhibits included beside a full line of standard electrical test instruments, apparatus for physical and physiological research and general demonstration.

From the celebrated house of Ruhmkorff (Carpentier, successor) they showed an immense Ruhmkorff Coil, which gave a spark of about twenty inches; a new Thomson galvanometer, and various electrometers, magnetometers, volt- and ampèremeters, etc., of fine workmanship.

The house of Breguet sent several consignments of the famous Gramme machines, Serrin Regulators, Plantè Secondary batteries. These attracted much attention, and formed a valuable addition to the display.

Queen & Co. also exhibited Gerard's Dynamo Machines, which were here for the first time exhibited in this country. Among those shown were some small dynamos with accessories for class demonstration. These machines, with the dynamo machines of De Meritens and Fein, made a full exhibit of this class of apparatus. The dynamo machines of C. Fein, were mounted on tables, and were designed for educational purposes.

In this connection an important exhibit was made of the famous Jablochkoff candles which were run by one of the large alternating current machines of the well-known house of De Meritens. The machines are largely used by the French and English governments in

their lighthouses. The same firm sent over one of these large machines expressly adapted for use with Jablochkoff candles, and was used to furnish the light for Queen & Co.'s space during the entire exhibit.

Another important feature was the collection of fine test apparatus from the well-known German houses of Edelmann and Hartmann. Their instruments possess many novel features, and are peculiarly well adapted for accurate work. They have been, heretofore, comparatively little used in this country, and were objects of interest to scientific men on account of their accuracy of construction and reasonable cost. The instruments of special value in the collection from Hartmann were the Kohlrausch galvanometers, reading telescopes and resistance coils. The last named were adjusted to the new Ohm, which gave them a peculiar interest.

The large Edelmann absolute galvanometer, and the large Wiedemann galvanometer for accurate measurements, are very fine instruments, as are also the astatic galvanometers and the quadrant electrometers. Several of these were used in the Test-house.

Of English electrical test instruments, Queen & Co. exhibited a number of resistance coils and Sir William Thomson's reflecting galvanometers, from the celebrated house of Elliott Bros.; also the instruments of Ayrton & Perry, and Paterson & Cooper. They also had a collection of apparatus from C. J. Simmons (for many years with Elliott Bros.), whose test instruments including resistance coils and Wheatstone bridges were very good, and useful for educational purposes. They also exhibited some of Prof. S. P. Thompson's electromotors and apparatus from the well-known house of Siemens Bros. & Co.

Of Physiological apparatus the varied collection from the house of Ch. Verdin, of Paris, was quite complete. These were much admired. The Cambridge Scientific Co. also sent a large and complete exhibit of their well-known apparatus.

The beautiful collection of Instruments of Precision, such as divided bars, micrometers, spectrometers and cathetometers from the Societé Génevoise, were of special interest to our prominent physicists. The instruments of this house are very accurate and of beautiful construc-

tion and finish, and recent tests have developed fresh proofs of their precision.

There was also exhibited a fine collection of medical electrical apparatus from G. Dupré, and the electrical apparatus of Cloris Baudet, as well as the speed-counters and recorders of Deschien.

Queen & Co. also had a large number of Holtz machines, both of their own special importation, made for them abroad, and also their new American form, manufactured by themselves. This firm was the first to introduce the Toepler-Holtz machine in this country. Their collection was very complete, and as the machines were constantly in operation, they were features of the Exhibition.

Their display of Geissler' and Crookes' tubes was especially fine. They erected in the main building a dark room specially for the exhibition of these tubes, for apparatus for projection, and for other valuable optical apparatus from the famous house of Duboscq. They also showed a great variety of chemical apparatus, incandescent lamps, apparatus for sugar chemists, crystal models, and physical apparatus generally.

The description of Queen's exhibit in the catalogue is well worthy examination. Besides the electrical apparatus there was a large showing of accessories and optical instruments. Among the former was a fine mercury pump for exhausting the globes of electrical lamps under high vacua. This instrument was interesting as being a contribution from Dr. Geissler, of Bonn, and from his workshop. Drs. Steeg and Reuter sent over a collection of great value consisting of sections of crystals and polariscopic and optical instruments.

At the series of lectures which were given during the Exhibition by eminent scientific men, the instruments used were mainly obtained from the exhibit of Queen & Co., who in the most cordial manner offered the free loan of all the apparatus necessary for illustration. Especially was this the case at the lecture of Prof. Forbes on "Dynamo Machines;" and at that of Mr. A. E. Outerbridge on "Radiant Matter," where a very large and complete set of Geissler and Crookes tubes was furnished and exhibited, and the lectures of Prof. Houston to the

school children. At the lecture on the "Wave Theory of Light," given at the Academy of Music, by Sir William Thomson, under the auspices of the Institute, Queen & Co. supplied the lantern and a number of other instruments, and also gave their personal assistance, thus aiding materially in the success of the lecture.

A number of very fine Galvanometers and Reading Telescopes from Hartmann and Edelmann were loaned to the committees and were in use at the Test-house during all the tests.

The services of Queen & Co. to the Exhibition Committee in the loan of apparatus was rendered still more valuable by their detail of skilled assistants to place the instruments in working order and to superintend their operation when in use for lectures. To deprive themselves for considerable periods of time of the services of these gentlemen no doubt caused the firm considerable inconvenience, and the kindness is appreciated by the Institute.

In a report giving a brief glance at the more prominent points of interest it is of course impossible to mention many entries of goods that were equally attractive. Hanson, Van Winkle & Co., Newark, N. J., electro-plating; the printing press of N. Y. Electrical World, run by electric motor; Bidwell's railway; the Union Switch and Signal Co.'s extensive plant and ingenious devices for railroading; the electrotypes of Messrs. Ready, of the British Museum, kindly loaned by the American Numismatic and Archæological Society of New York; the Clay Commercial Telephone, with its system of exchange, all suggest a great variety of other interesting matter fully described in the catalogue.

Among the foreign visitors to the Exhibition were many scientific men of world-wide reputation. Prominent in the lists are recorded Sir Wm. Thomson, Lord Rayleigh, Prof. Sylvanus P. Thompson, W. H. Preece, Prof. George Forbes, Lieuts. F. R. De Wolski, and Chisholm Batten, official representatives of Great Britain; Prof. Tchisuke Fujoka, Tokio, Japan; F. N. Gisbourne, Government Electrician for Canada; Señor Enrique A. Mexia, official representative of Mexico,

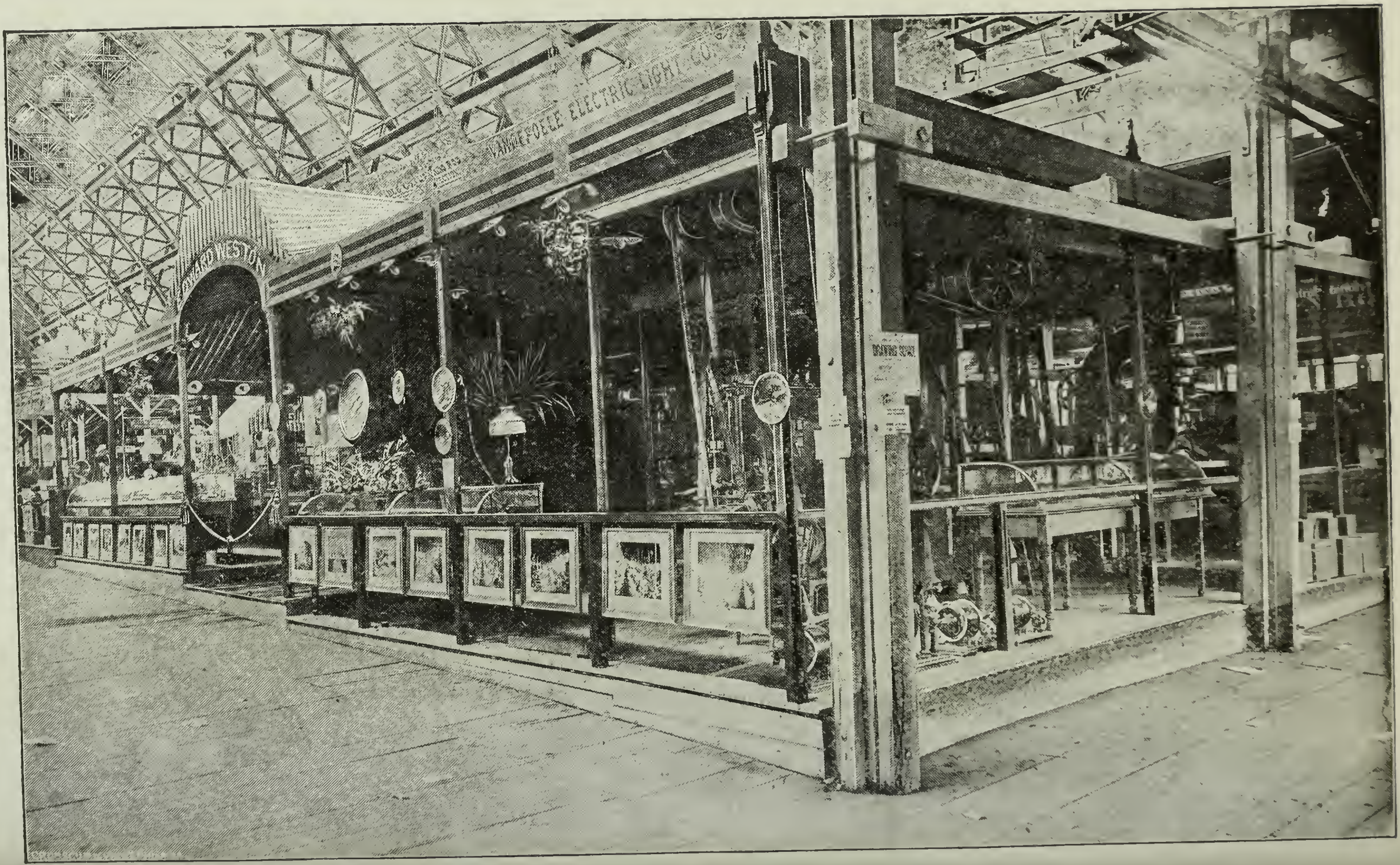



EXHIBIT OF EDWARD WESTON.

and others whose names appear among the members of the Electrical Conference.

The report of the Treasurer shows the Exhibition to have been a financial success. The entire expense of erection of buildings, the cost of shafting, steam piping and general preparations, as well as the running expenses, were promptly met and a balance of a few thousand dollars left in the treasury. This was accomplished without Government aid, or the use of public moneys.

As has already been stated, there was no fire or alarm during the entire period. Nor was there a panic at any time in the immense crowds of visitors, and an entire freedom from accidents and loss of life or injury to employés or visitors. When it is remembered that the buildings, temporary in character and constructed of inflammable materials, were filled with machines that ignorance or carelessness might turn into engines of destruction, the care of Divine Providence is manifested. To Him shall we render our thanks.

Respectfully submitted,

CHARLES H. BANES, *Chairman.*

# APPENDIX.

## COMMITTEE ON EXHIBITIONS.

Charles H. Banes, *Chairman.*

William P. Tatham,
Charles Bullock,
Frederick Graff,
Joseph E. Mitchell,
Samuel Sartain,
Washington Jones,
A. E. Outerbridge, Jr.,
William D. Marks,
Cyrus Chambers, Jr.,
Addison B. Burk,
E. Alex. Scott,
G. Morgan Eldridge,
Lewis S. Ware,
Chas. S. Shain,
C. Wesley Lyons,
Edward Longstreth,
Chas. E. Ronaldson,
Henry C. Davis,
Luther L. Cheney,
Thomas Hockley,
W. W. Griscom,
Wm. V. McKean,
William Sellers,
Frederick Fraley,
John J. Weaver,
Joseph M. Wilson,
Coleman Sellers,
Isaac Norris, Jr.,
Theodore D. Rand,
J. Vaughan Merrick,
Henry R. Heyl,
William B. Cooper,
Hugo Bilgram,
Charles Faser,
John Baird,
Chas. M. Cresson,
Horace W. Sellers,
David Brooks,
Henry Morton,
W. J. Phillips,
H. H. Levette,
J. H. Linville,
John B. De Motte,
Edwin J. Houston,
Wm. H. Thorne,
Persifor Frazer,
Enoch Lewis,
William Helme,
C. Chabot,
Pliny E. Chase,
Hector Orr,
Robert E. Rogers,
Jules Viennot,
Luigi D'Auria,
S. R. Marshall,
M. B. Snyder,
Raphael Estrada,
N. H. Edgerton,
Coleman Sellers, Jr.,
Louis H. Spellier,
S. Lloyd Wiegand,
Wm. Barnet Le Van,
Murray Bacon,
Carl Hering.

William H. Wahl, *Secretary.*

*Special Committees.*

*Superintendent.*—William D. Marks.
*Electrician.*—Edwin J. Houston.
*On Finance.*—Frederick Fraley, *Chairman.*
*On Space.*—Charles Bullock, *Chairman.*
*On Transportation.*—Enoch Lewis, *Chairman.*
*On Classification.*—Pliny E. Chase, *Chairman.*
*On Bibliography.*—Isaac Norris, Jr., *Chairman.*
*On Buildings and Machinery.*—Frederick Graff, *Chairman.*
*On Rules and Regulations.*—Coleman Sellers, *Chairman.*
*On Custom House Regulations.*—Charles Bullock, *Chairman.*
*On Correspondence and Publication.*—William H. Wahl, *Chairman.*
*On Historical Electrical Apparatus.*—Edwin J. Houston, *Chairman.*
*On Electrical Installation.*—Edwin J. Houston, *Chairman.*
*On Admissions.*—Samuel Sartain.
*On Board of Examiners.*—M. B. Snyder.

# LIST OF GUARANTORS INTERNATIONAL ELECTRICAL EXHIBITION.

| | |
|---|---|
| A. J. Drexel | $1,000 |
| Geo. W. Childs | 1,000 |
| W. P. Tatham | 1,000 |
| Fairman Rogers | 1,000 |
| Henry C. Gibson | 1,000 |
| John Baird | 1,000 |
| J. V. Merrick | 1,000 |
| B. H. Bartol | 1,000 |
| Alex. Biddle | 1,000 |
| Henry Bower | 1,000 |
| Wm. Sellers & Co | 1,000 |
| Chas. H. Banes | 1,000 |
| A. Whitney & Sons | 1,000 |
| Henry Disston & Sons | 1,000 |
| Burnham, Parry, Williams & Co | 1,000 |
| H. Belfield & Co. | 1,000 |
| James Moore | 1,000 |
| Hoopes & Townsend | 1,000 |
| I. P. Morris Co | 1,000 |
| John Wiler | 1,000 |
| John Wanamaker | 1,000 |
| Washington Jones | 1,000 |
| P. A. B. Weidener | 1,000 |
| Brush Electric Light Co. of Philadelphia | 1,000 |
| Morris Wheeler & Co | 500 |
| W. D. Rogers, Son & Co | 500 |
| F. Gutekunst | 500 |
| Hughes & Patterson | 500 |
| Alexander Bros | 100 |
| Persifor Frazer | 100 |
| J. R. Claghorn | 100 |
| E. and F. N. Spon | 100 |
| Frederick Shober | 100 |
| Edward Samuel | 100 |
| Isaac Norris, Jr | 100 |
| Robert Frazer | 100 |
| Theodore D. Rand | 100 |
| A. E. Outerbridge, Jr | 100 |
| Jas W. Queen & Co | 100 |
| H. B. Bartol | 100 |
| Smith, Kline & Co | 100 |
| Aschenbach & Miller | 100 |
| Charles Norris | 100 |
| Samuel Sartain | 100 |
| Henry Howson | 500 |
| G. B. Roberts | 500 |
| Chambers Bros. & Co | 500 |
| Allan, Wood & Co | 500 |
| S. Lloyd Wiegand | 500 |
| Thos. Hockley | 500 |
| John G. Baker | 500 |
| G. W. Fiss | 500 |
| Percival Roberts | 500 |
| Wm. M. Singerly | 500 |
| Wm. D. Marks | 500 |
| Wm. Helme | 300 |
| Erben, Search & Co | 250 |
| C. H. Hutchinson | 250 |
| H. Bottomley | 250 |
| Chas. Platt | 250 |
| Geo. V. Cresson | 250 |
| Chas. Bullock | 250 |
| J. E. Mitchell | 250 |
| Frederick Graff | 250 |
| E. F. Houghton & Co | 250 |
| Walter Wood | 200 |
| Frederick Fraley | 100 |
| Lewis S. Ware | 100 |
| William H. Wahl | 100 |
| James Rowland | 100 |
| Theo. R. Wolf | 100 |
| Alfred Mellor | 100 |
| Henry N. Rittenhouse | 100 |
| Edward Rowland | 100 |
| Centennial National Bank | 50 |
| John S. Haines | 50 |
| John M. Maris & Co | 50 |
| Keasbey & Mattison | 50 |
| J. J. Allen's Sons | 50 |
| A. Hamilton Patterson | 50 |
| M. Buechler | 50 |
| Louis E. Levy | 50 |
| N. Penrose Allen | 25 |
| Wm. H. Thorne | 25 |
| F. Foell | 25 |
| Harry Rowland | 25 |
| A. R. Raymond | 25 |
| Dueding Bros. & Co | 25 |
| Chas. J. Shain | 25 |

and sundry amounts from the following named persons: Clem & Morse, Milan Bentley, Parker D. Pierce, Harry S Gross, M. D., Dr. M. F. Grove's Sons, James Rossiter, Geo. S. Wright, H. J. Peters, Wm. Knighton, Wm. H. Beadling, P. C. Broodwell, Christ. Petzelt, C. C. Hughes, John E. Grove, J. R. Landis, Bernhard A. Hertsch, Alexander Wilson, J. F. Hopkinson, Jr., S. Douglass, F. H. Bassett, J. W. Guerdrum, W. P. Keffer.

## JOINT RESOLUTION OF CONGRESS AND CIRCULAR OF THE TREASURY DEPARTMENT OF THE UNITED STATES.

TREASURY DEPARTMENT,
*Washington, D. C., November* 14, 1883.

TO COLLECTORS OF CUSTOMS AND OTHERS:

The following Joint Resolution, approved February 26, 1883, is published for the information and guidance of Customs Officers:

"WHEREAS, the Franklin Institute of the State of Pennsylvania, for the promotion of the Mechanic Arts, proposes to hold an exhibition of electrical apparatus, machinery, tools and implements, and other articles used in scientific and mechanical and manufacturing business and investigations; and

WHEREAS, It is deemed desirable to promote the success of such an exhibition by all reasonable encouragement, in order that it may be made useful to the promotion of knowledge; therefore be it

"*Resolved by the Senate and House of Representatives of the United States of America in Congress assembled*, That all articles which shall be imported for the sole purpose of exhibition at the Exhibition to be held by the Franklin Institute of the State of Pennsylvania, for the promotion of the Mechanic Arts, in the city of Philadelphia in the year eighteen hundred and eighty-three or eighteen hundred and eighty-four, shall be admitted without payment of duty or customs fees or charges, under such regulations as the Secretary of the Treasury shall prescribe:

*Provided*, That all such articles as shall be sold in the United States or withdrawn for consumption therein at any time after such importation. shall be subject to the duties, if any, imposed on like articles by the revenue laws in force at the date of importation; *And provided further*, That in case any article imported under the provisions of this Joint Resolution shall be withdrawn from [for] consumption, or shall be sold without payment of duty as required by law, all the penalties prescribed by the revenue laws shall be applied and enforced against such articles and against the persons who may be guilty of such withdrawal or sales."

In pursuance of this Resolution, the following regulations are hereby prescribed:

Invoices will be required, which shall recite the fact that the goods embraced therein are intended for this Exhibition. Each shipper will be required to make such invoice in triplicate, giving a description of his goods, their value, and the marks and numbers thereon; but any number of such invoices may embraced in one declaration by the agent, such declaration to be taken before a Consular Officer of the United States and certified in the usual manner. One copy of the invoice will be sent to the Collector of Customs at the port of first arrival, one copy to the Collector of Customs at Philadelphia, and one copy to the consignee or agent of the shipper.

Articles intended for this Exhibition and arriving at the ports of Boston, New York, Baltimore, San Francisco, or New Orleans, or any port on the Canadian frontier at which goods may be shipped for immediate transportation under the Act of June 10, 1880, entitled "An act to amend the statutes in relation to immediate transportation of dutiable goods, and for other purposes" (S. S., 4582), may be shipped by bonded common carriers from the port of first arrival to Philadelphia.

On the arrival of such goods at Philadelphia, either direct or *via* either of the ports named, due notice of such arrival will be given to the Collector by the consignee, whereupon the Collector will take possession of the same. Entry for warehouse, in the usual manner, will be permitted, and the usual bond taken to secure the duties, and, after the bulding shall have been duly bonded, the goods will be stored in the Exhibition building.

Upon completion of the warehouse entry and storage of the goods in the Exhibition building, the packages will be opened and due examination and appraisement of the contents, with proper allowance for damages sustained on the voyage of importation, if any, will be made by the appraiser at such Exhibition building, which shall, for that purpose, be regarded as a public store. After the appraisement shall have been completed, the entry will be liuuidated as usual, and proper record made of the same.

To identify the articles, a ticket will be pasted on each article, giving the name of the shipper stated in the invoice and the number of the warehouse entry. A storekeeper will be stationed at the Exhibition building, at the expense of the Exhibition, who will keep a register of the goods received in a debit and credit account, checking against the receipts the deliveries as they may be made. The goods may be withdrawn for exportation at any time within three years from the date of importation without payment of duties or customs fees or charges. On withdrawal for consumption, however, the usual fees accrue. If not withdrawn for consumption or exportation within that time, they become liable to sale to realize the duties. On sale of any of the goods for consumption in the United States, withdrawal entry will be permitted on payment of duties at the rate in force at the dates of importation of the several articles respectively. On such withdrawal for consumption, after one year from date of original importation, an additional duty of 10 per cent. on the duties originally assessed will be exacted.

Such of the instruments of precision as may require verification and an adjustment for adaptation to the scientific purposes of the Exhibition in

advance of its opening, may be delivered to the Franklin Institute for such preliminary adaptation, upon receipts signed by the President or Vice-President of the Institute.

The Circular of March 22, 1883, No. 27, upon the same subject, is hereby repealed.

CHAS. J. FOLGER.
*Secretary.*

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## RULES AND REGULATIONS.

1. The building at Thirty-Second street and Lancaster avenue, will be opened for the reception of the articles and goods intended for Exhibition on Monday, August 11th, and remain open for that purpose until Saturday, August 30th. On Tuesday, September 2d, the Exhibition will be formally opened to the public at 12 o'clock M., and continue open daily (Sunday excepted) from 10 A. M. to 10 P. M., until Saturday, October 11th.

2. Each exhibitor will be required to pay an entrance fee of $5, for which he will receive one season ticket of admission not transferable and issued to any one of the members of a firm or corporation that may be exhibitors; additional tickets for other members of a firm or the executive officers of corporations being procurable at the same rate for each person. Tickets of admission for the attendants absolutely necessary for the care and operation of the exhibits can be procured free of charge subject to the regulation of the Committee in charge of tickets, and these tickets are to be forfeited if wrongfully used.

The charge for space occupied by exhibits, either on the floor or under the ground, or suspended above the aisles, or on the walls (to be paid upon the receipt of permit) will be as follows:

| | | |
|---|---|---|
| | All spaces under 10 square feet | $2 00 |
| | From 10 to 100 square feet | 20 cents per square foot. |
| Rates per Square Foot. | 100 square feet @ 20 cents | $20 00 |
| | 200 square feet @ $17\frac{1}{2}$ cents | 35 00 |
| | 300 square feet @ $15\frac{1}{2}$ cents | 46 50 |
| | 400 square feet @ 14 cents | 56 00 |
| | 500 square feet @ 13 cents | 65 00 |
| | 600 square feet @ $12\frac{1}{4}$ cents | 73 50 |
| | 700 square feet @ $11\frac{4}{7}$ cents | 81 00 |
| | 800 square feet @ 11 cents | 88 00 |
| | 900 square feet @ $10\frac{1}{2}$ cents | 94 50 |
| | 1,000 square feet @ 10 cents | 100 00 |

All spaces measuring over 1,000 square feet...10 cents per square foot.

The rate per square foot for any fractional excess of space over any even hundred in the above table will be the rate of such hundred diminished by a due proportion of the difference between that rate and the rate of the next hundred.

3. All applications for space must be made before August 30th, on printed blank forms, to be furnished by the Committee; and they will be con-

sidered and the space allotted to applicants in the order of their reception; and space allotted to exhibitors, but not occupied by August 30th, may be assigned to other exhibitors. Whenever the articles will admit, exhibitors are requested to display them in glass cases.

4. All articles delivered at the building shall be reported to the Committee, who will direct their location and assign them the proper space. Any article shipped to the Exhibition by rail or otherwise, must have freight and charges prepaid, and invoice and Bill of Lading mailed to "Committee on Exhibition, Franklin Institute, Philadelphia, U. S. A."

5. Exhibitors or their agents will be furnished by the entry clerk with duplicate cards, upon which must be placed a description of each article entered for exhibition; these will be countersigned on the receipt of the articles into the Exhibition. One of these cards shall be conspicuously attached to the article which it describes, and the other must be retained by the exhibitor, and be presented as his order for the delivery of the article specified, at the close of the Exhibition.

6. The Committee reserve the right to exclude from the building and premises all articles of a dangerous or offensive or otherwise objectionable character.

7. No article can be removed from the building during the time of the Exhibition, unless by consent of the Committee.

8. A police force will be in attendance upon the premises during the Exhibition and watchmen at night; but all articles on exhibition will be at the risk of the owner.

9. Power will be furnished to drive machines at the rate of three cents per horse-power per hour, the power to be rated at sixty square feet per minute of belt if the belt is single, and forty square feet per minute if the belt is double. The tension on belt to be subject to the judgment of the engineer of the Exhibition in charge, whose decision is final. If machines are driven direct from engines furnished by the exhibitors, the steam used will be rated by indicator, and charged at the same rate per horse-power. Full credit will be given for power for creating light ordered by the General Superintendent.

10. Signs will not be allowed of greater size than 500 square inches, nor shall such signs be elevated above the exhibits. The distribution of circulars, cards or samples about the building will not be permitted; exhibitors can distribute such things only from their own stand.

11. The arrangement and distribution of the electric conductors in all parts of the building shall be wholly under the direction of the Electrician in charge, who will decide on the position and determine the character of the insulation, under the rules laid down by the Committee.

12. No Awards or Premiums are offered by the Institute, but in place thereof a report to the Institute will be prepared by a Board of Examiners, which report will be as full as the time and opportunity will permit. Exhibitors are requested to give at the time of the opening of the Exhibition detailed descriptions of their exhibits addressed to the Board of Examiners, describing the merits of each exhibit as understood by the Exhibitor, such matter, at the discretion of the Examiners, to be used in their report. If, however, any of the exhibitors desire expert examination or competitive

tests of their displays, such tests will be conducted by the Institute to the extent practicable in the time, provided the cost of the materials and instruments used be borne by the exhibitors desiring the test. The Special Committees to whom these tests will be referred will be appointed by the Board of Managers of the Institute, subject to the approval of a majority of those asking for the test if it is competitive. The original copy of all reports shall remain the property of the Institute, which shall have the first right of publication.

The Institute reserves the right to enter into such other scientific work touching the Exhibition (not requested by the exhibitors) as in its judgment may tend to the advancement of science.

The Examiners shall be appointed by the Board of Managers and shall be men of acknowledged integrity, skill, and experience in the class of goods assigned to them, and no Examiner shall serve on any class in which he may be an exhibiter or be otherwise directly interested. The mornings of each day until fifteen minutes before the time of opening the Exhibition, shall be appropriated to the Examiners who shall be attended only by such persons as they may invite to be present.

13. Exhibitors are required to attach to their exhibit a printed description in English of the use and operation of the object exhibited, for public information, if at any time the exhibit should be left without attendants who can explain it.

## SYNOPSIS OF CLASSIFICATION.

### Section I.—*Production of Electricity.*

Class I. Apparatus for Electricity of High Electromotive Force.
Class II. Voltaic Electric Apparatus.
Class III. Thermo-Electric Apparatus.
Class IV. Magneto-Electric Apparatus.
Class V. Dynamo-Electric Apparatus.
Class VI. Mechanical Motors — Steam, Gas, Water, Heat and Wind Engines.

### Section II.—*Electric Conductors.*

Class I. Telegraph Wires.
Class II. Telephone Wires and Cables.
Class III. Electric Light Circuits.
Class IV. Underground Conduits for Electric Conductors.
Class V. Sub-Marine Cables.
Class VI. Insulating Materials for Conductors.
Class VII. Electrical Joints and Connections.

### Section III.—*Measurements.*

Class I. Measurements of Dimensions.
Class II. Measurements of Speed, Force and Energy.
Class III. Electrical Measurements.
Class IV. Photometric Measurements.

### SECTION IV.—A.—*Applications of Electricity.*

(Apparatus requiring Electric Currents of comparatively Low Power.)

Class I. Electric Telegraphs.
Class II. Telephones, Microphones, Photophones and Radiaphones.
Class III. Fire and Burglar Alarms.
Class IV. Annunciators.
Class V. Electric Clocks and Time Telegraphs.
Class VI. Electric Registering Apparatus.
Class VII. Electric Signal Apparatus.
Class VIII. Electro-Medical.
Class IX. Applications of Electricity to Dentistry.
Class X. Applications of Electricity to Warfare.
Class XI. Applications of Electricity to Mining and Blasting.
Class XII. Applications of Electricity to Spinning and Weaving
Class XIII Electrical Traps and Snares.
Class XIV. Applications of Electricity to Pneumatic Apparatus.
Class XV. Applications of Electricity to Musical Instruments.
Class XVI. Applications of Electricity to Writing and Printing.
Class XVII. Electrical Toys.
Class XVIII. Electrical Conjuring Apparatus.
Class XIX. Miscellaneous Applications of Small Currents.

### SECTION IV.—B.—*Applications of Electricity.*

(Apparatus requiring Electric Currents of comparatively Great Power.)

Class I. Electrical Illumination.
Class II. Electro-Metallurgy.
Class III. Other Applications of Electro-Chemistry.
Class IV. Storage Batteries and Accumulators.
Class V. Electric Motors. Transmission of Power.
Class VI. Electro-Magnetic Brakes.
Class VII. Miscellaneous Applications of Large Currents.

### SECTION V.—*Terrestrial Physics.*

Class I. Atmospheric Electricity.
Class II. Terrestrial Magnetism.
Class III. Apparatus used by Governments for Weather Signal Stations.

### SECTION VI.—*Historical Apparatus.*

### SECTION VII.—*Educational and Bibliographical.*

## THE PROPOSED CONFERENCE OF ELECTRICIANS AT PHILADELPHIA.

In order to secure to the fullest extent the unusual advantage arising from the coincidence in the time of holding the proposed International Electrical Exhibition in Philadelphia, and of the meeting of the American Association for the Advancement of Science in the same city, in connection with the anticipated visit of the members of the British Association to this city, the Franklin Institute has appointed a special committee to confer with scientific men as to the best method to be adopted for securing, during the month of September, the assembling at Philadelphia of a Conference of Electricians.

To defray the expenses of such a conference, a bill has been prepared asking for a small appropriation from Congress.

Scientific men interested in this measure are earnestly requested to give it all the aid in their power.

Communications on the subject are respectfully requested by the committee.

M. B. Snyder,
Edwin J. Houston,
Wm. H. Wahl,
Wm. P. Tatham,
*Committee.*

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## PUBLIC SCHOOL CIRCULAR.

The Franklin Institute, desirous of manifesting the interest it takes in cultivating a taste for useful knowledge in the Public Schools, and making the benefits of the Electrical Exposition available to the pupils in a more positive degree than can be accomplished by simply visiting the building, has decided to award a number of prizes to the pupils, of the character and upon the conditions set forth below:

1. A prize to be awarded for the best essay presented by the Boys' Grammar School and by the Girls' Grammar School of each section, by each class in the Girls' Normal School, and by each class in the Boys' Central High School.

2. The prize to be awarded to each school and class shall be five dollars and a handsomely engraved certificate, setting forth the distinction

obtained by its holder. The prize will be awarded at a public meeting to be held at the lecture room of the exhibition.

3. The subject of the essay shall be, "What I Saw at the Electrical Exhibitien." The essay must contain an account of some electrical phenomenon, piece of machinery, apparatus or appliance on exhibition. No essay containing simply an exposition of principles, or their application to uses not represented in the exhibition, will be considered as meeting the requirements of the competition.

4. The essay must be written on medium ruled foolscap paper, and must not be less than two nor more than four pages in length. It must have the name of the school and section written at the top of the first page, and be subscribed with a motto at the end. This motto is to be written on the face of a sealed envelope containing the pupil's name, age, section, school and class. The pupil's name must not appear in any form on his or her essay.

5. The points to be considered in deciding upon the merits of the essays are the discrimination exhibited in selecting the object which forms the subject-matter of the essay, and the clearness, neatness and accuracy with which this object, the scientific principles which it involves, or the uses to which it is applied, have been described. The essay need not necessarily be confined to one object. Rhetorical qualities are not to be considered and unimportant grammatical errors are to be diregarded. The essay is intended to be a test of the pupil's observing powers, and his ability to describe accurately, in simple terms, what he has actually seen and examined for himself.

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## REPORT OF THE LECTURE COMMITTEE TO THE COMMITTEE ON EXHIBITIONS.

COL. CHAS. H. BANES, *Chairman Committee on Exhibitions.*

SIR:—The special committee appointed shortly before the opening of the Exhibition, to arrange a series of lectures in connection with the International Electrical Exhibition, submit herewith their report:

The large assembly room in the annex was set apart for the Committee's use, in which it was decided to hold, on two evenings of each week during the progress of the Exhibition, lectures on topics more or less directly connected with Electricity. The evenings of Tuesday and Thursday were selected as being the most suitable for the purpose. Correspondence was opened with a number of well-known specialists, which resulted in receiving the services of the following gentlemen, who lectured in the order indicated, upon the subjects set opposite to their names:

| Date. | | | Lecturers. | Subject. |
|---|---|---|---|---|
| Sept., | Tuesday, | 16. | Prof. Geo. Forbes, F.R.S.E., of London...... | Dynamo-Electric Machinery. |
| " | Thursday, | 18. | Rossiter W. Raymond, Ph. D., of New York, Sec. Am. Inst. Mining Engineers. | The Divining Rod. |
| " | Tuesday, | 23. | Nathaniel S. Keith, of New York, Sec. Am. Inst. Electrical Engineers.. .................. | Electro-Metallurgy. |
| " | Thursday, | 25. | Prof. Chas. A. Young, of Princeton, N. J... | The Physics of the Sun. |
| " | Tuesday, | 30. | Prof. Harrison Allen, M.D., of Phila......... | Electricity in Medicine |
| Oct. | Thursday, | 2. | Prof. Chas. F. Himes. Ph.D., of Carlisle, Pa. | Actinism. |
| " | Tuesday, | 7. | Prof. Persifor Frazer, D.Sc., of Phila......... | Crystallization. |
| " | Thursday, | 9. | Mr. Alex. E. Outerbridge, Jr... .................... | Radiant Matter. |

The foregoing lectures were held in the Lecture Hall provided therefor in the Annex, and which was provided with a suitable temporary platform and lecture tables. The large apartment was appropriately decorated and was provided with seats for about five hundred persons. Aside from its great height, which made it difficult for a lecturer to be distinctly heard, the room was very well adapted for the Committee's uses. The lectures were all well attended, the room being frequently crowded to its utmost capacity, testifying to the wisdom of the management in deciding to introduce lecture courses as a portion of the educational work of the Exhibition.

All the lectures were more or less fully illustrated, by the use of the projecting lantern, and with apparatus and materials drawn from the Exhibition. The lectures were free to all visitors to the Exhibition.

In addition to the above-named lectures, the Committee were enabled with the co-operation of the President of the Institute, to secure the services of Prof. Sir William Thomson, F.R.S., etc., of the University of Glasgow, who delivered a lecture on "The Wave Theory or Light," at the Academy of Music, on Monday evening, Sept. 29, 1884. Arrangements have been made for the publication of these lectures in the JOURNAL.

The net expense attending the holding of the above-named series of lectures was $507.44, for a detailed statement of which the Committee refer to the account books of the Exhibition.

In addition to the foregoing, arrangements were made, with the co-operation of the Superintendent of Public Sohools and the Board of Public Education, by which the pupils of the public schools of the

City of Philadelphia (of and above the grade of Grammar Schools), were afforded an excellent opportunity of benefiting by the Exhibition. The arrangement referred to, embraced the daily visit of a certain body of the pupils, selected by sections in rotation. This visit to the Exhibition took the place of a school session.

With the object of preparing the visiting pupils to properly observe and understand something of what they would see at the Exhibition, they were permitted first to listen to a lecture having this object in view. This was very elementary in character, and was designed, by means of experimental illustrations and simple explanations thereof, to impress on the minds of the pupils some of the fundamental facts and principles of the science of Electricity.

It is estimated that these lectures were attended by about fifteen thousand scholars of the public schools. Two lectures were delivered daily (Saturdays and Sundays excepted), beginning on the 16th of September and ending on the 9th of October, one being delivered at 9.30 and the other at 10.30 A.M. This duty was most faithfully and satisfactorily performed by Prof. Edwin J. Houston, of the Central High School, with the assistance of Prof. J. B. DeMotte, of DePauw University, Greencastle, Ind.

To still further impress the Exhibition on the minds of the scholars, a plan of competitive prizes was framed, in which each school was permitted to participate. This plan embraced the preparation and submission to a Committee of Judges of a composition by each pupil on "What I Saw at the Electrical Exhibition."

This subject is referred to here as supplementary to the work of this Committee.

The Committee desire, in conclusion, to acknowledge their great obligations to Messrs. James W. Queen & Co., for their liberal assistance in loaning from their superb exhibit of physical apparatus whatever the Committee required, and to express their appreciation of the manner in which Mr. Charles M. Knapp assisted the lecturers.

Appended to this report, are copies of the announcements of the lectures and other matters of reference.

Respectfully submitted by your obedient servants,

William H. Wahl, *Chairman.*
Edwin J. Houston,
M. B. Snyder,
*Committee on Lectures.*

## REPORT OF THE SPECIAL COMMITTEE ON BIBLIOGRAPHY TO THE COMMITTEE ON EXHIBITIONS.

To Col. Chas. H. Banes, *Chairman Committee on Exhibitions.*

Sir:—The Committee on Bibliography was called into existence in pursuance of the following resolution, passed by the Committee on Exhibitions at a meeting held November 3, 1883, and which was approved by the Board of Managers at their stated meeting held November 13, 1883, viz:

*Resolved*, That a special committee be appointed, to be charged with the preparation of a bibliographical collection relating to the subjects of Electricity and Magnetism, and with its proper exhibition, which collection shall, subsequent to the exhibition, be placed permanently in the library of the Institute as a memorial of the exhibition.

The Committee on Bibliography, as originally appointed under this resolution, consisted of Isaac Norris, M. D. (chairman), Edwin J. Houston, and William H. Wahl, to which, in recognition of valuable services rendered to the committee, the name of John B. De Motte was subsequently added.

To carry out the objects for which it was constituted, the committee caused to be prepared a circular letter, in the English, French and German languages, setting forth their intention of making a collection of the literature of Electricity, and requesting donations of books, pamphlets, and published matter of whatever description, relating to the subject. Such donations the committee promised to suitably display in a special department to be provided therefor in the International Electrical Exhibition, to acknowledge the same in a printed catalogue, giving the titles of the works and the names of the donors, and to place the same, after the close of the exhibition, in the library of the Franklin Institute, where, under the name of the "Memorial Library of the International Electrical Exhibition," it should find a permanent place as a library of reference exclusively.

This circular-letter the committee caused to be sent to publishers, authors and men of science in the United States and in European countries whose addresses were accessible, and had the gratification of receiving favorable responses from a large proportion of those addressed.

Recognizing the impossibility of making a collection worthy of its name and the occasion, without having represented in it the more important older works, now out of print, the committee made an

appeal to the friends of the Institute for subscriptions to a fund to be devoted to the purchase of Electrical works of a historical character.

In response to this appeal the committee received gifts of money to the amount of nine hundred and forty-three dollars. (A list of subscribers, with the amounts subscribed by each, is hereunto appended. See Exhibit A.)

## EXHIBIT "A."

*Gifts of Money Received by the Committee.*

| Name. | Amounts subscribed. |
|---|---|
| Thomas Ridgway | $100 00 |
| Mrs. G. Dawson Coleman | 100 00 |
| Edwin H. Fitler | 100 00 |
| William Sellers | 50 00 |
| E. W. Clark & Co | 50 00 |
| Henry C. Lea | 50 00 |
| William Weightman | 50 00 |
| A. J. Drexel | 50 00 |
| William F. Jones | 50 00 |
| Charles H. Banes | 25 00 |
| B. H. Bartol | 25 00 |
| C. M. Ghriskey | 25 00 |
| C. Schaeffer | 25 00 |
| Mr. and Mrs. J. D. Lippincott | 25 00 |
| William M. Singerly | 25 00 |
| Henry C. Gibson | 25 00 |
| G. M. Eldridge | 20 00 |
| D. S. Craven | 18 00 |
| Washington Jones | 10 00 |
| D. N. A. Randolph | 10 00 |
| A. B. Couch | 10 00 |
| Edward Stern & Co | 10 00 |
| Z. C. Howell | 10 00 |
| C. H. Borie | 10 00 |
| Walter Wood | 10 00 |
| E. C. Jayne | 10 00 |
| E. O. Thompson | 10 00 |
| Dr. James Collins | 10 00 |
| John Fauser | 5 00 |
| Samuel Allen | 5 00 |
| Charles H. Marot | 5 00 |
| R. Ledig | 5 00 |
| L. R. Buchanan | 5 00 |
| D. McAlpine | 2 00 |
| E. B. Cooper | 1 00 |
| Irwin Lee | 1 00 |
| A. H. Patterson | 1 00 |
| Total | $943 00 |

The generous responses to their appeal have enabled the committee to add much valuable material to the "Memorial Library," which they could not have obtained by other means.

Of this amount there has been expended for books and for other needful purposes, by the committee's direction, $669.63, leaving a balance to the committee's credit, on Jan. 1, 1885, of $273.37.

The following summary and analysis will give a sufficiently clear idea of the work accomplished by the committee, viz.:

| | |
|---|---|
| Whole number of publications received from all sources, and now in the Memorial Library | 3,422 |

They are divided into

| | |
|---|---|
| Bound volumes | 660 |
| Unbound volumes | 269 |
| Pamphlets | 1,948 |
| Serials | 82 |
| Manuscripts | 13 |
| Excerpta | 4 |
| | 2,976 |

(The apparent discrepancy in totals is explained by the fact that many bound volumes of a single Journal count only as *one* in the analytical table.)

The classification of these publications by nationalities gives the following:

*Bound Volumes.*

| | |
|---|---|
| American | 353 |
| English | 147 |
| French | 137 |
| German | 22 |
| Dutch | 1 |
| | 660 |

*Unbound Volumes.*

| | |
|---|---|
| French | 94 |
| German | 77 |
| American | 31 |
| Italian | 20 |
| Russian | 18 |
| English | 9 |
| Dutch | 9 |
| Austrian | 6 |
| Belgian | 4 |
| Swiss | 1 |
| | 269 |

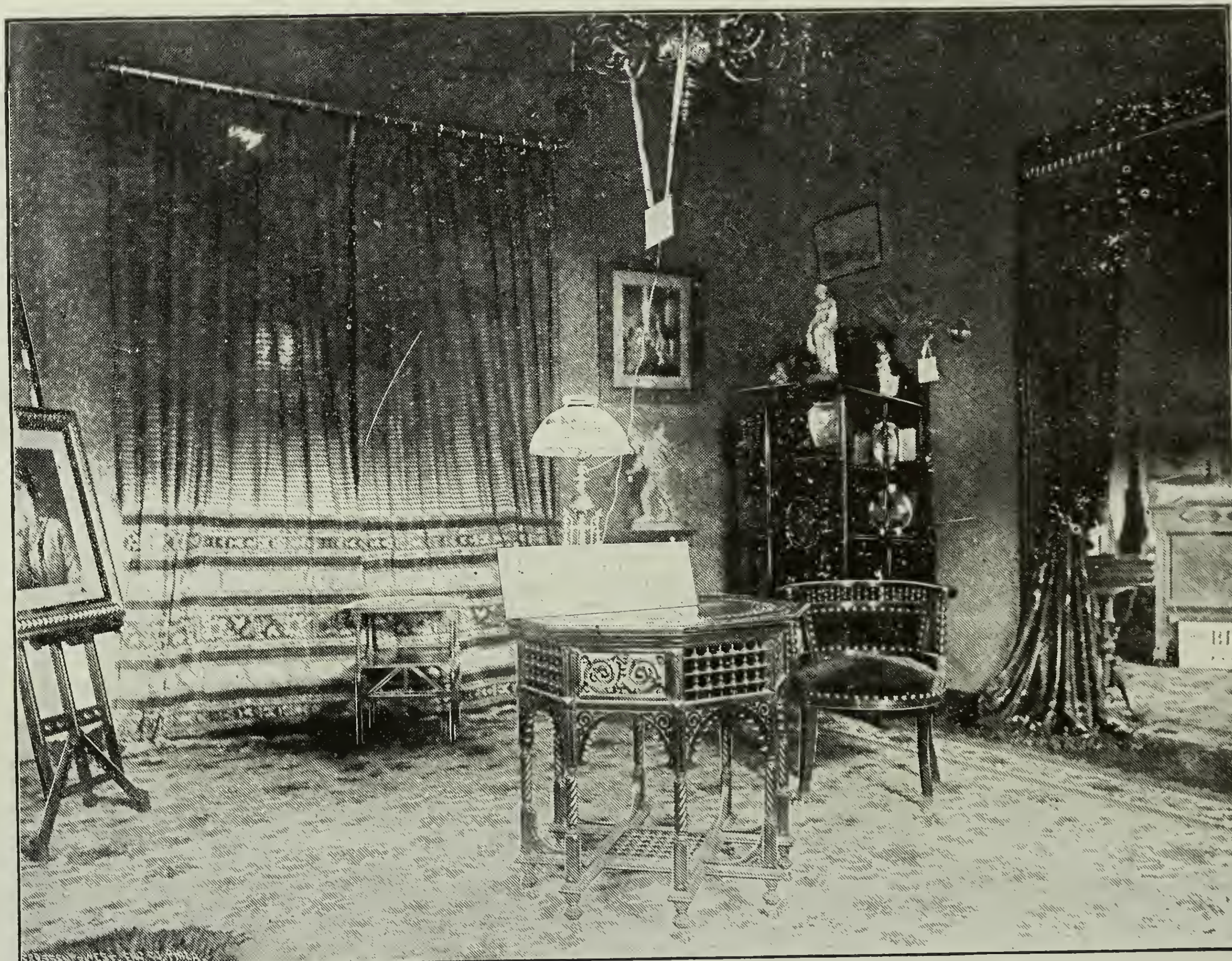

EXHIBIT OF THE BRUSH ELECTRIC COMPANY. [An Interior.]

*Pamphlets.*

| | |
|---|---|
| English | 639 |
| American | 422 |
| German | 388 |
| Italian | 178 |
| French | 136 |
| Austrian | 66 |
| Belgian | 65 |
| Russian | 20 |
| Bohemian | 14 |
| Dutch | 6 |
| Swiss | 5 |
| Spanish | 4 |
| Danish | 4 |
| Portuguese | 1 |
| | 1,948 |

*Journals.*

| | |
|---|---|
| American | 43 |
| French | 16 |
| German | 8 |
| English | 7 |
| Austrian | 3 |
| Swiss | 2 |
| Italian | 1 |
| Spanish | 1 |
| Canadian | 1 |
| | 82 |

*Manuscripts.*

| | |
|---|---|
| English | 4 |
| American | 3 |
| German | 3 |
| French | 3 |
| | 13 |

*Excerpta.*

| | |
|---|---|
| American | 3 |
| English | 1 |
| | 4 |

Of the whole number of publications in the committee's collection, there were secured by donations from authors, publishers and others, 2,287, comprising 506 bound volumes, 324 unbound volumes and 1,565 pamphlets, etc.; by purchase with funds subscribed, 1,145, comprising 108 bound volumes, 254 unbound volumes and 783 pamphlets, etc. Total, 2,287 + 1,145 = 3,432.

In accordance with the terms of the circular-letter issued by this committee, the Committee on Exhibitions provided a suitable apartment in the large hall of the depot of the Pennsylvania Railroad Company, in which the collection was shown to advantage. The collection was at all times accessible to visitors, and was constantly consulted.

A subject-matter catalogue, embracing the titles of such works as had been received up to the time of the opening of the exhibition, with the names of the donors, was compiled by Mr. E. Hiltebrant, Librarian of the Institute, under the direction of the committee, and was published as part of the general catalogue of the exhibition. Since the close of the exhibition this work has been completed by Mr. Hiltebrant, by the addition of the large number of works received after September 1, and the enlarged and corrected edition of the catalogue has just been issued under the committee's direction, and forms an octavo volume of nearly 200 pages.

Concerning the character of the collection which the committee has been enabled to make, it may suffice to say that it contains a very satisfactory representation of the current literature of Electricity and Magnetism, copies of many special investigations in the form of authors' reprints, and excerpta from the publications of learned societies, besides a small proportion of the non-current and historical literature.

With the transmittal of this report, the functions of the Committee on Bibliography terminate.

It remains only for the committee to request that you, as the Chairman of the Committee on Exhibitions, will take the steps necessary to fulfill their remaining promise, namely, to place their collection in the library of the Franklin Institute as a Memorial Library of the International Electrical Exhibition, to be used exclusively as a library of reference.

Respectfully submitted by your obedient servants,

Isaac Norris, M.D., *Chairman.*
Edwin J. Houston,
John B. De Motte,
William H. Wahl,
*Committee on Bibliography.*

Philadelphia, January, 1885.

# RULES

*For the Installation of Electric Apparatus, at the Franklin Institute International Electrical Exhibition, adopted by the Committee on Electrical Installation.*

## *Prefatory.*

The following rules and regulations have been adopted for the purpose of securing the highest possible safety both to life and property. It is therefore earnestly requested that all exhibitors will give their hearty co-operation in carrying them into effect.

## *Rules.*

1. All space granted to exhibitors in the International Electrical Exhibition must be occupied in accordance with the rules and regulations of the Committee on Electrical Installation, and all exhibitors must agree to submit to the said rules before such space is allotted to them.

2. No circuits shall be run in the Exhibition Buildings until full plans and particulars thereof are first submitted to the Committee, and approved by them.

3. No changes shall be made in any circuits without the consent of the Committee.

4. Any question pertaining to the installation of electrical apparatus that does not fall within the scope of these rules must be referred to said Committee for decision.

## *Circuits.*

5. All circuits must be insulated and metallic throughout their entire extent; *i. e.*, no ground connections are to be used.

6. The conductors of all main circuits must have such a weight per running foot as will enable them to carry the current employed without heating.

7. When circuits are taken from large to small conductors, and the large conductor carries such a current as would dangerously raise the temperature of the smaller wire, if accidentally diverted through it, an approved automatic safety device must be introduced into the circuit of the smaller conductor, whereby the circuit will be automatically interrupted whenever the current passing through the smaller conductor is in excess of safety. Similar automatic safety devices must be used in all circuits run in the vicinity of electric light and power circuits.

8. All circuit wires for electric light or power currents must be insulated with some approved incombustible material.

9. Circuit wires exposed to moisture must have, in addition to their insulating covering, a coating of some water-proof material.

10. No paraffined or wax-covered wires are to be used in situations or under circumstances where they may be exposed to a high temperature.

11. When the electro-motive force of the current exceeds 300 volts, the different parts of a circuit outside the electro-generator or the apparatus which it energizes, must not approach one another nearer than eight inches.

12. Aerial wires must not have a greater drop than one foot between points of support.

13. All circuits are to be run so as to permit ready and frequent inspection by the committee.

14. When practicable, the positive or outgoing conductor must be clearly marked so as to distinguish it from the negative or return conductor.

15. As far as practicable, continuous wires must be employed. Whenever joints are necessary, they must be made in such a manner as to insure a good and durable contact, and said joints must afterwards be insulated.

16. Wires fastened to walls and ceilings must be rigidly attached to the same by suitable insulating fastenings. In no case will loose loops in the same be permitted.

17. Where circuit wires pass through walls, floors, or ceilings, a special insulating, incombustible tubing must be used to encase the wire.

18. All electric light and power circuits must be tested, as often as the Committee may direct, for accidental grounds, or contacts, and if such are found, the currents shall in no case be permitted in such circuits until such grounds or defects are removed.

19. No circuits shall be placed underground within the building.

20. All underground conduits, in use as such, must be placed outside the main building, as may be directed by the Committee, and all circuits connected therewith must be provided with safety devices.

*Systems of Electric Lighting.*

21. Dynamo-Electric Machines must in all cases be thoroughly insulated from the ground, and be surrounded by a railing so as to prevent the approach of the public nearer than two feet.

22. All Dynamo-Electric Machines must be furnished with means to prevent the dangerous heating of their coils on the extinguishment of part of their lights, and if such means be not automatic in action, a competent person must be in charge of the machine while it is running.

23. Electric arc lamps must be provided with an automatic switch or cut-off, so that the lamp will be automatically cut out from the circuit whenever the current traversing its coils reaches a dangerous limit.

24. All electric arc lamp-frames must be insulated and provided with a hand switch to cut out the light when so desired.

25. All electric arc lights used in the building must be protected by glass globes, furnished with a wire netting outside the globe, to keep the globe in place in case of accidental fracture. Broken or cracked globes must be promptly replaced by sound ones. The bases of the globes must be enclosed so as to prevent the fall of heated particles.

26. A suitable device must be placed on all arc lamps to prevent the fall of the lower carbon, on the failure of its holder.

27. The Committee reserve the right to adopt special preventives in all cases where the safety of the public seems to demand it.

28. The Committe reserve the right to modify these rules in particular cases where it is considered that circumstances warrant such modifications.

29. In all cases requiring prompt action, the exhibitors must be governed by the decision of the Electrician until the matter can be acted upon by the committee.

EDWIN J. HOUSTON, *Chairman*,
HENRY MORTON,
CHARLES M. CRESSON, M. D.,
W. P. TATHAM,
M. B. SNYDER.

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*Executive Committee of Board of Examiners.*

1884—INTERNATIONAL ELECTRICAL EXHIBITION—1884

OF THE

FRANKLIN INSTITUTE, OF THE STATE OF PENNSYLVANIA,

FOR THE

PROMOTION OF THE MECHANIC ARTS

# REPORTS OF THE EXAMINERS

—OF—

# SECTION X.

*(SECTION I, CLASS VI, OF THE CATALOGUE.)*

## STEAM BOILERS

[ISSUED BY AUTHORITY OF THE BOARD OF MANAGERS AND PUBLISHED AS A SUPPLEMENT TO THE JOURNAL OF THE FRANKLIN INSTITUTE, JULY, 1885.]

PHILADELPHIA:
THE FRANKLIN INSTITUTE
1885.

## EDITING COMMITTEE.

PERSIFOR FRAZER, *Chairman.*

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WILLIAM H. WAHL.

# INTERNATIONAL ELECTRICAL EXHIBITION, 1884.

FRANKLIN INSTITUTE, Philadelphia, Pa.

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## REPORT OF EXAMINERS.

### SECTION X.—STEAM BOILERS.

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*To the Board of Managers, Franklin Institute:*

GENTLEMEN:—I have the honor to transmit herewith the report of the Examiners of Section X, on Steam Boilers.

Respectfully,

M. B. SNYDER,

*Chairman Board of Examiners.*

PHILADELPHIA, *December*, 1884.

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PROF. M. B. SNYDER,

*Chairman Board of Examiners, International Electrical Exhibition:*

SIR:—The Examiners in Section X (on Steam Boilers), respectfully present the following report.

H. W. SPANGLER, *for Section X.*

PHILADELPHIA, *December*, 1884.

# REPORT ON STEAM BOILERS.

*U. S. S. Tennessee*, NEW ORLEANS, LA.
February 13, 1885.

*To the Chairman of the Board of Examiners on Steam Boilers.*

GENTLEMEN:—Enclosed I send you a copy of the results of tests made during the late International Electrical Exhibition, together with an account of the methods used, and the deductions from the results.

The drawings of all the boilers are in the possession of Professor Marks, and I would recommend that they be reproduced for the report. I have not that data with me which can be taken directly from the drawings, and have left blanks wherever, in the description of the boilers, data should be filled in.

The thanks of the Committee are due to the Crosby Steam Gauge and Valve Company, for the use of their standard steam gauges and test pumps; also to Mr. M. B. Edson for his recording and alarm gauge, which was used in each of the tests; also to the Blake Manufacturing Company, for the use of two pumps for feeding boilers during the tests; and to Riehlé Brothers and Mr. Troemner for the use of scales during the tests.

The following named young men rendered valuable assistance in observing and recording the data during the tests, and are especially entitled to the thanks of the Committee.

| | | |
|---|---|---|
| Geo. R. Green, | H. Szlapka, | Leon Kraft, |
| Charles H. Small, | F. Thibault, | Richard McCall, |
| George K. Fischer, | E. E. Alcott, | R. L. Rutter, |
| W. F. Lubbe, | Wm. A. Bigler, | D. E. Tracy, |
| L. F. Roudinellá, | Theodore Gould, Jr., | Joseph Israel, |
| | Thos. Grier. | |

All the calculations have been checked at different times by different computers.

Hoping the results and methods have been satisfactory to the Committee,

I am, very truly yours,

H. W. SPANGLER (*for Section X*),
*Assistant Engineer, U. S. Navy.*

*Code of the Proposed Quantitative Tests for the Evaporative Efficiency of Boilers at the International Electrical Exhibition, by the Franklin Institute, of* 1884.

### SPECIAL NOTICE.

Boilers may be exhibited and used at the International Electrical Exhibition, but will not have quantitative tests made of their efficiency unless formal application is made, and the subjoined code accepted before July 15, 1884.

Competitive tests will not be made unless at the joint request of the

parties desiring a competitive test, and after they have agreed to and subscribed to this code, and fixed upon a rating for the points enumerated in Article 4.

The Committee of judges reserve the right to limit the number of tests made, should time and opportunity not permit all the tests desired to be completed.

### SECTION I.—PRELIMINARIES TO THE TESTS.

ARTICLE 1. (Capacity.) The boilers entered may be of any capacity having an evaporative power, not less than seven hundred and fifty pounds of water per hour.

Each boiler must be so drilled as to enable its whole internal capacity to be determined by being completely filled and emptied of water. Proper cocks, piping, etc., must be so placed as to enable this to be done readily.

ART. 2. (Pipes and Valves.) Each exhibitor will furnish all the pipes and valves necessary to make connection with the main water and steam pipes in a proper manner, and subject to the orders of the Superintendent. He will also make any alterations in water and steam pipes required for the tests, furnishing all tools, piping, cocks, and mechanical labor at his own cost.

ART. 3. (Space.) Each exhibitor will be furnished with space at the regular rates established for the exhibition, in which space he must build his foundations and boiler setting, and make connection with the chimney flue, if required, at his own cost, and subject to the approval of the Superintendent.

ART. 4. (Specifications.) Each exhibitor must furnish to the Chairman of the committee of judges on steam boilers, such description and drawing, both of the boiler in position and of the details of the boiler, as will facilitate the labor of that committee, together with his claims as to meritorious points for his exhibit.

The following points will have special consideration :

1. Economy of fuel.
2. Economy of material and labor of Construction.
3. Evaporative power. (Space occupied.)
4. Simplicity and accessibility of parts.
5. Durability of whole structure.

Exhibitors desiring a competitive test made, must agree upon a rating for these points before it will be made.

Exhibitors must also file the following data :

Area of heating surface to the nearest hundredth of a foot.

Area of grate surface to the nearest hundredth of a foot.

Area of calorimeter to the nearest hundredth of a foot.

Area of chimney flue to the nearest hundredth of a foot.

Height of chimney required.

Number of pounds of coal per square foot of grate to be burned per hour.

Should the calculations of the committee of judges differ in result from

those of the exhibitor, he will be required to give all the details of his calculations, and an agreement must be reached before proceeding with the test.

SECTION II.—PREPARATIONS FOR THE TESTS.

ART. 5. (Coal). Anthracite coal will be used and will be furnished free of charge, provided the steam made is used for the general purposes of the Exhibition.

The same quality and size of coal will be used in all the tests, unless special arrangements be made for another kind of fuel.

An analysis will be made of the coal used. The coal will be weighed to the boiler.

ART. 6. (Water). The water used will be taken from the city mains. The feed water for the boilers will be weighed by means of scales and a large tank, and will be run into a smaller supplemental tank, from which it will be pumped into the boiler by means of a feed pump actuated by steam from the boilers.

The temperature of the feed water will be taken by means of a standard thermometer, in the supplemental tank.

ART. 7. (Pressure.) The steam pressure used shall not exceed ninety pounds per square inch by the guage, unless by special arrangement with the committee of judges.

A standard guage will be used and also a standard thermometer immersed in a mercury pocket in the steam space.

ART. 8. (Safety Valve.) The safety valve will be set to blow off at ten pounds above the pressure fixed upon.

ART. 9. (Leaks.) Within twenty-four hours preceding the test of a boiler, it must be subjected to hydraulic pressure, ten pounds greater than its steam pressure during the test, and proved to be perfectly tight.

ART. 10. (Attendants.) The attendants in charge of the boiler tested must be approved by the party whose boiler is tested and by the judges. All attendants are to be subject to the orders of the judges during the progress of the test.

ART. 11. (Ashes.) All ashes will be weighed on being withdrawn from the ash pit, and must not be damped until weighed.

ART. 12. (Calorimeters.) The calorimeters used will consist of a barrel, scale and hand thermometer. Two calorimeters will be used and simultaneous observations made at fifteen minute intervals.

ART. 13. (Fires.) The exhibitor shall be allowed one day previous to the test to clean boilers and grates.

The steam having reached the required pressure, the ash pit shall be thoroughly cleaned and swept, and thereafter the fire maintained as nearly uniform as possible, the test closing with the same depth and intensity of fire as it opened.

This point is to be decided by the judges who may make allowance if it be clearly shown to have been imposible to maintain uniform fires.

If in the judgment of the committee of judges the firing is inefficiently or improperly done, the test may be terminated at any time, and a repetition of the test refused.

ART. 14. (Pyrometer.) The temperature of the gases of combustion immediately upon entering the chimney flue shall be taken by means of a suitable pyrometer, read at fifteen minutes intervals, and close to the boiler.

ART. 15. (Manometer and Barometer.) The vacuum in the chimney flue shall be taken by means of a water manometer read at fifteen minutes interval. A barometer will be read simultaneously.

ART. 16. (Duration.) Unless otherwise arranged, the tests will last ten hours.

ART. 17. (Economy and Efficiency of the Boiler.) The level of the water in the boiler and the state of the fire must be kept as nearly constant as possible during the whole of the trial.

The weight of the water in the boiler for each one quarter of an inch, on the glass water guage, will be carefully determined and recorded previous to the test, and proper correction for unavoidable changes of level made.

The weight of water fed to the boiler, subject to proper corrections, will be multiplied by its observed thermal value as steam. From this product the thermal units of heat brought in by the feed will be subtracted.

The remainder will be divided by nine hundred and sixty-six and seven-hundredths British thermal units, giving the number of pounds of water evaporated from and at two hundred and twelve degrees Fahrenheit.

This latter quantity will be divided by the weight of coal burned, less weight of dry ashes, giving the number of pounds of water evaporated per pound of combustible. This shall be taken as the measure of the efficiency of the boiler.

The nominal horse-power of the boiler will be deduced by dividing the number of pounds of water evaporated from, and at two hundred and twelve degrees Fahrenheit per hour by thirty.

The evaporative power of the boiler will be determined by dividing the normal horse-power of the boiler by the number of cubic feet of space it occupies.

The space occupied by a boiler and its appurtenances will be regarded as the product of the square feet of floor space occupied by its extreme height in feet.

## Methods Used in Testing Boilers.

All the boilers tested by this committee were located in a boiler-house to the north of the exhibition building proper, this boiler-house being open to the weather on the sides. It is probable that the boilers would have shown a higher efficiency, had the boiler-house been entirely enclosed, as the weather was quite cold during part of the tests.

The methods used were, as nearly as possible, the same for each boiler, and are given in detail below.

### WATER.

All the water fed to the boilers during the tests was taken from two large tanks, each holding about 2,400 pounds of water, when full. In starting each test, the water-level in the boiler was noted, and all water put into the boiler after the test began was taken from the above-mentioned tanks which were alternately weighed and emptied. At the end of a test, the water-level in the boiler was brought to the same point as at starting, and the amount of water left in the tanks weighed and properly accounted for.

The steam pumps used on all the boiler tests worked very satisfactorily, there being no leaks about either pumps or pipes.

Before testing a boiler, a joint on each water pipe leading to the boiler was broken, and all the pipes disconnected excepting the one feeding from the pump used in testing.

### SCALES.

The scales used for weighing feed water and coal were of Riehlé's make, and those used for the calorimeters were partly of Fairbank's and partly of Riehlé's make. All the scales were very accurate and were checked by comparison with Fairbank's standard weights of 50 pounds each.

### TEMPERATURE OF FEED WATER.

The temperature of all water fed to the boilers was taken at intervals during the tests, and the mean of these temperatures was taken as the temperature of the feed. The thermometers used were made by J. & H. J. Green, of New York, and were very accurate.

## COAL.

The coal used in these tests was purchased at different times and the size was as desired by the exhibitors of the various boilers. All coal was weighed in barrows and allowance made for all that was not used. The coal in all the tests was as it came from the dealer and was slightly wet. In each test a number of barrows full of coal were dried at the temperature of the air, and again weighed, but no appreciable loss of weight was perceptible. In the test of the Root boiler, the floor under the coal was constantly wet from water from the calorimeters used, but the greater part of the coal used was in the same condition as that used in the other tests.

A careful analysis of the coal was made under the direction of Professor Samuel P. Sadtler, from samples taken, from time to time, during the test by Mr. Spangler.

## WOOD.

The wood used was such as happened to be most convenient, and was not all of the same kind, but the amount used was so small in comparison with the total amount of fuel, that the same allowance was made in each case for the relative values of coal and wood.

## ASHES.

All ashes were weighed dry, and at the end of the test the fire was drawn, and where any unburnt coal came from the furnace, it was credited to the coal account, the remainder was charged to the ash account.

In the case of the Dickson boiler, the ashes were very wet as they were drawn from the ash pan, as the steam blower discharged directly into the ash pan. A number of barrows of ashes were weighed and the percentage of moisture was calculated from the weight after drying, and due allowance made for the same in the ash account.

## BAROMETER.

The readings of the barometer were taken from the observations made by the United States Signal Service in Philadelphia, during the time of the tests.

THERMOMETER.

The temperature of the air was taken from the same source and agreed very closely with that taken during the tests.

STEAM PRESSURE.

The steam gauge used on the tests was furnished by the Crosby Steam Gauge and Valve Company. One of these gauges was tested by Thomas Shaw, of Philadelphia, with a mercury column for every five pounds from 0 to 120 pounds, both ascending and descending.

Before and after each test the gauge used on the boilers was carefully compared with this standard, both ascending and descending throughout the range of pressure used on the tests. The gauges were very accurate and agreed as well at the end as at the beginning of the set of tests. Readings were taken at frequent intervals, and the mean of these readings taken as the mean pressure of the steam.

In addition to the Crosby gauge used, an Edson Recording Gauge was attached to each boiler as it was tested, and records made during the entire test. The indications of this gauge were accurate and reliable, but the clockwork required frequent adjusting to keep the recording slip moving at a uniform speed. The alarm attached to the gauge was not used.

TEMPERATURE OF THE STEAM.

A large monitor thermometer was used for indicating the temperature of the steam. It was screwed into the steam space of the boiler, and its indications noted from time to time. These thermometers were a little slow in acting, as there was a considerable body of iron and mercury to change in temperature, but the indications are considered very reliable.

TEMPERATURE OF SMOKE-STACK.

In determining this temperature a monitor thermometer was inserted in the smoke-stack, just back of the damper in the Root, Baldwin, and Harrison boiler, and at the bottom of the smoke-pipe in the Dickson boiler. It was not practicable in all cases to put the thermometer in vertically. In the Harrison test it was vertical; in the Dickson test it was inclined at an angle of about 30 degrees to the vertical; and in

the Root and Baldwin tests, the thermometer was inclined about 10 degrees from the horizontal. The bulb of the thermometer was put as near as possible into the centre of the flue, while the stem projected into the air. The openings into the flue around the thermometer were carefully closed so that no air could enter. Readings were taken as often as practicable from these thermometers, and the mean of the readings taken.

## DRAFT IN CHIMNEY.

A number of devices were used for measuring the draft in the chimney. That used on the Root boiler was suggested by Professor Lanza, and was the design of Mr. Fisher, of the Massachusetts Institute of Technology. It consisted of two chambers *a* and *b*, Fig. 1, each covered by a rubber diaphragm *c* and *d*. The interior of the

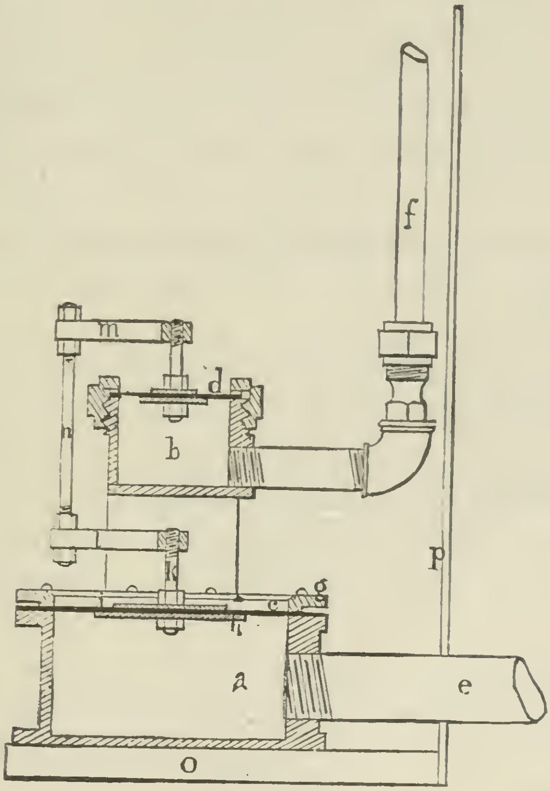



Fig. 1.

chamber *a* is connected with the interior of the chimney by means of a pipe *e*, supplied with a three-way cock so that the interior of *a* can be connected with the chimney or with the air. The interior of *b* is connected by means of a pipe to a vertical glass tube *f*, open at the top.

The chamber $b$, the glass tube $f$, and the connecting pipe are filled with water, the air being entirely excluded. The chamber $b$ and all its attachments are carried on the annular ring $g$, which holds the rubber diaphragm of $a$ in place. To the centre of the diaphragm $c$ two plates $h$, $h$, are attached which support a vertical rod $k$. This rod screws into a cross-head $l$. To the diaphragm of $b$ a similar cross-head $m$ is attached in the same way, and these two cross-heads are connected by means of two side rods, only one of which, $n$, is shown. The whole apparatus rests on a base board $o$, which carries a vertical piece $p$ to which a paper scale graduated in inches is attached. The method of using the apparatus is as follows: The three way cock in $e$ being turned so that $a$ is in communication with the air, the reading of the scale opposite the head of the water column is noted. The three-way cock is turned so that the inside of $a$ is connected with the chimney, and the reading of the top of the column in $f$ is again noted, and the difference between the readings is caused by the difference in pressure inside and outside the chimney. This difference divided by the ratio of the areas of the chambers $a$ and $b$ is the vacuum in the chimney in inches of water.

Comparison was made between this apparatus and the one referred to as the invention of Professor Webb, and the two methods were found substantially to agree.

As the Webb apparatus was more convenient, the one just described was used only on the Root boiler.

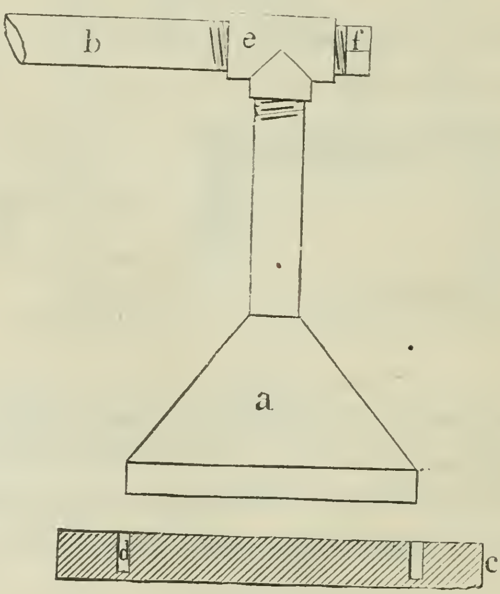



FIG. 2.

In testing the other boilers the following described apparatus, the invention of Professor J. Burkitt Webb, a member of the Committee, was used.

It consisted of an inverted funnel-shaped vessel, *a*, Fig. 2, whose interior is connected through the pipe *b* to the chimney. A piece of gas piping was put into the chimney and connected directly to the pipe *b*. The **T** *e*, had one end closed by a plug, *f*, so that, if desired, the interior of the funnel *a* could be connected to the air. The funnel *a* and pipe *b* were suspended over a board, *c*, having a circular groove, *d*, cut into its upper face. This board rested on a pair of Fairbanks' scales weighing to ounces. The groove *d* was filled with mercury and the edge of *a* dipped into this mercury.

The method of using the apparatus was as follows: The plug *f* being removed, the scales were balanced; the plug was then replaced, and *b* being connected to the chimney, the scales were balanced again and the difference or loss of weight noted. The loss of weight divided by the area of the mouth of *a* is the loss per square inch, and represents the difference in pressure inside and outside the chimney, and this multiplied by 1·728 gives the corresponding draft in inches of water. The apparatus worked very satisfactorily and the results are very reliable.

## QUALITY OF STEAM.

One of the most difficult subjects presented to the Committee was the quality of the steam generated, and we do not think the results obtained are to be implicitly trusted. The data was taken as carefully as could be, but the imperfections of the apparatus were such, that it is a matter of much doubt as to how much reliance can be placed on the results.

There were a number of devices presented to the Committee for use and discussed in their meetings, and the three following described were adopted and used in the tests.

It will be noticed that two different methods of testing the quality of the steam from each boiler were employed, except in the case of the Baldwin boiler, and the results vary so much that no conclusions can be drawn as to the degree of accuracy of either.

While it may be considered that the apparatus giving the most regular results is most to be depended upon, I am satisfied that the conditions in the best boiler are such that the quality of the steam must

be very variable, and it is doubtful whether a mean result is a satisfactory one or not.

The entire subject requires much more investigation than your Committee had the time to undertake.

## BARREL CALORIMETER.

One apparatus used for testing the quality of the steam was an ordinary barrel resting on Riehle's scales. A quantity of water was put into the barrel and its weight noted. Just before making the experiment, the temperature of the water was noted. A steam pipe from the boiler led down to within a short distance of the barrel and was covered with felting. To the end of this pipe a short length of hose was attached. Everything being ready for the experiment, the steam was turned on the hose and allowed to blow into the air until apparently dry steam showed at the end of the hose. This end was then put into the barrel and the temperature of the water allowed to rise from 10 to 20 degrees, the water being constantly agitated. The hose was then taken out and the temperature of the water in the barrel noted. The weight was then taken and the pressure of steam during the experiment noted. From this data the quality of the steam was calculated.

In making the calculations, allowance was made for the water equivalent of the barrel used. The barrel being partly filled with water to the level used in the experiments and its temperature noted, a quantity of warm water of known temperature was added and the resulting temperature noted. Knowing the weights of water used, the equivalent of the barrel was found as follows: Multiply the added weight of water by the number of heat units lost by the warm water and divide by the heat units gained by the cold water. This quotient less the weight of cold water in the barrel is the water equivalent of the barrel.

Allowing the water to remain in the barrel for three minutes made no appreciable change in the temperature, showing that there was but little loss from radiation during each experiment, which did not generally last over two minutes.

The following formula was used in making the calculations from data derived while using this apparatus, and an examination of the results will show that they vary surprisingly.

$w$ = weight of cold water plus water equivalent of barrel.

$g$ = heat units corresponding to temperature of cold water, counting from 32° F.

$g_1$ = heat units corresponding to temperature of the mixture, counting from 32° F.

$H$ = heat units (latent) corresponding to the temperature and pressure of steam.

$g_2$ = heat units (sensible) corresponding to the temperature and pressure of the steam, counting from 32° F.

$w_1$ = weight of water and steam added.

$\varsigma$ = water contained in $w_1$.

$$\varsigma = 1 + \frac{1}{H}\left\{(g_2 - g_1) - \frac{w}{w_1}(g_1 - g)\right\}$$

The numerical quantities used in making these calculations were taken from Röntgen's "Thermodynamics" (DuBois' translation), and are substantially the same as other tables derived from the same source, and were used because they were familiar to the young men making the calculations.

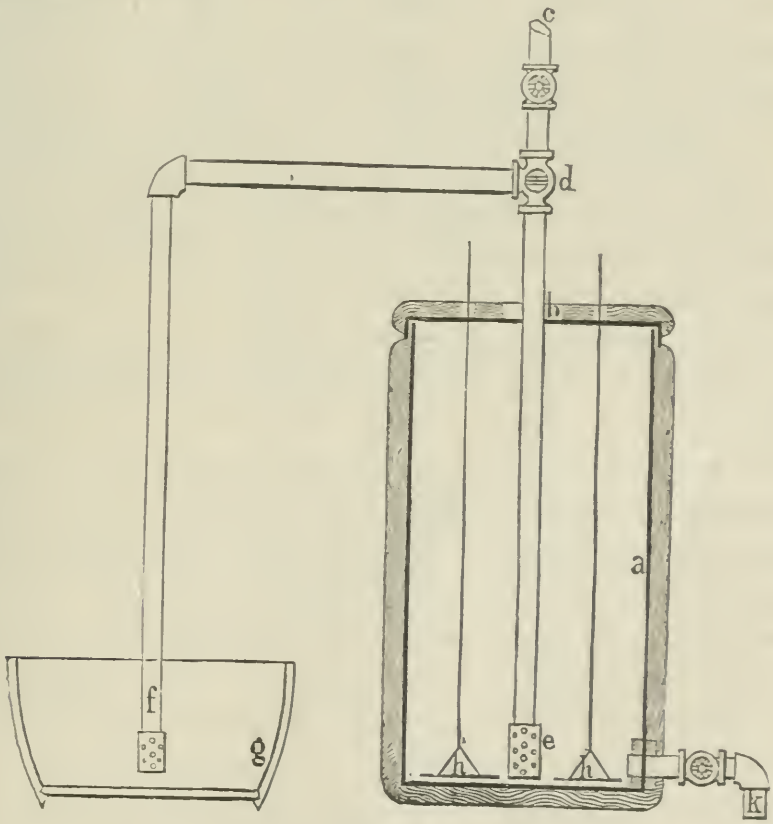



FIG. 3.

The second apparatus used was on the same general principle, and only differed from the first in matters of detail. It is shown in Fig. 3. *a* represents a tin tank, high in proportion to its diameter, and heavily covered with felt and canvas. A tin cover, *b*, fitting over this tank, had an opening in its centre for admitting steam or cold water. *c* is the pipe from the boiler, branching at the three-way cock *d*. One branch goes down into the tank *a*, and has the rose *e* at its lower end. The other branch terminates in the rose *f*, in the tank *g*, which is kept partly filled with water. *k* is the drain-pipe and valve for emptying *a*. The method of operating the calorimeter is as follows: The weight of the tank *a* is taken. It is then partly filled with water, and the weight and temperature is noted. Steam being off the pipe *c*, the three-way cock *d* is turned so that *c* and *f* are in communication. Steam is now turned on *c* and passes into the water in *g*. As soon as the pipe is heated and clear of any condensed water, the three-way cock *d* is turned and the steam allowed to pass into *a*. As soon as a sufficient quantity, say 10 pounds, has passed into *a*, the three-way cock is turned into its original position and steam is shut off *c*. *h*, *h* is an annular perforated plate, having two handles extending through the cover *b*, and is used to thoroughly mix the water in *a*. The temperature is now taken and also the weight of the tank and its contents. The pressure of the steam is noted, and the experiment is ended. The water equivalent of the tank is determined as for the simple barrel, and the calculations are made in the same way as before.

When this and the previous method were used at the same time, the results entirely disagreed.

The third method used was one devised by Mr. Barrus, a member of the Committee on Steam Engines, and was used on both boiler and engine tests.

Fig. 4 is a sketch of the apparatus. It consisted of a wooden vessel, *o*, mounted on a frame at the proper height for use. Inside this vessel were two partitions, so that any water passing from the centre of the vessel, must pass over one and under the second. In the centre of the vessel was a vertical cylinder, *m*, which confined the coldest condensing water to the centre of the apparatus. The condensing water passed down the pipe A, through a valve by which the quantity was regulated, and into the cylinder *m*, out at the bottom of *m*, and out through *c*. The pipe *j* was connected directly to the boiler or steam-pipe from which the steam was to be taken. Below the globe

valve is shown a branch-pipe, forming a gauge siphon. Below the vessel *o*, there is attached to the main pipe a glass water-gauge, *c*, and below this there was a globe valve, *d*, which regulated the discharge of the condensed steam. A short piece of hose was attached and the condensed water was drawn off into two buckets set on accurate pairs of Fairbanks' balances. These buckets were partly filled with cold water and their weights were taken. A quantity of the condensed water was run into one, and before the temperature had risen to 100° F., the hose was moved to the other bucket. The weight of the bucket of warm water was noted and the difference of the weights is the weight of the condensed steam. The bucket was emptied and partly filled with cold water again.

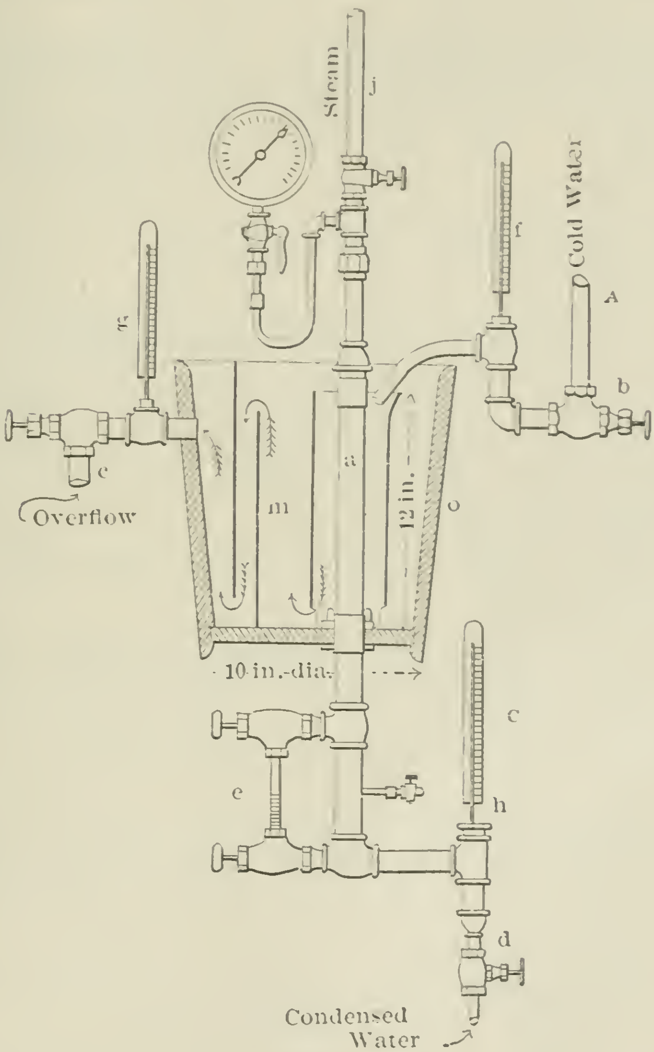



FIG. 4.

The condensing water, after passing *e*, emptied into a tank, which

was supported over two barrels. The water could be directed into either at will. The barrels were weighed empty and full, and the difference taken as the weight of the condensing water.

The temperature of the condensing water was taken at *f*, before going into *o*, and at *g*, after doing its work. The temperature of the condensed water was taken at *c*, and the temperature of the live steam was taken from the corresponding pressure.

The method of operating the apparatus was as follows:

One barrel under *c* was empty and its weight known, and one bucket was partly filled with cold water and its weight known. Any water passing through *c*, flowed into the unweighed barrel and was allowed to escape through a valve at the bottom. The small hose attached below *d*, discharges into the air. The thermometers and gauge being in place, the valves *b* and *c* were opened wide and water allowed to flow through *m*. The steam-valve was then opened and steam allowed to condense in the pipe, the valve *d* being closed. As soon as the water got to a determined level in the pipe and in *e*, the valve *d* was opened sufficiently to allow as much water to escape as was condensed. The steam valve was opened wide and the supply of cold water was regulated by the valve *b*, until the desired difference of temperature between A and *g* was obtained. The level of the water in *e* should be maintained. This being the case, the water at *c* was turned into the weighed barrel, and the hose from *d* put into the bucket containing the weighed quantity of water.

Readings of the gauge and thermometers were taken every five minutes during the tests.

While the barrel and bucket were filling, the others, which we will call 2, were being prepared. Barrel 2 had the valve at the bottom closed, and was weighed. Bucket 2 was partly filled with water, and weighed.

Bucket 1 being filled, the hose was turned into No. 2, and No. 1 was weighed, emptied, and again filled with cold water, and weighed. The difference between the first two weighings of bucket 1 is the amount of condensed water.

Barrel 1 being filled, the water from *c* was turned into barrel 2. Barrel 1 was weighed, emptied wholly or in part, and was again weighed. The difference between the first two weighings of barrel 1 is the amount of condensing water used. When it is desired to end

the experiment, the barrel and bucket in use should be changed at the same instant, and weighed, and the steam closed off.

One point to be particularly guarded against is the blowing of live steam into the buckets, as in that case the water in the buckets becomes part of the condensing water, and no provision is made for such a contingency.

The calculations were made in the following way: The total amount of condensing and condensed water was determined. The average of the readings of thermometers and gauge was found.

Using the same nomenclature as before, with the following addition and change, the quantity of moisture was determined by the following formula.

$g_1$ = heat units corresponding to temperature of condensing water after passing through calorimeter, counting from 32°.

$g_3$ = heat units corresponding to temperature of condensed steam, counting from 32°.

$$\varphi = 1 + \frac{1}{H}\left\{(g_2 - g_3) - \frac{w}{w_1}(g_1 - g)\right\}$$

QUALITY OF GASES OF COMBUSTION.

The apparatus used for making these tests was loaned by Professor Denton, and a sketch of it is given in Fig. 5.

The entire apparatus is mounted on a frame, so that it can easily be moved from place to place. It consists of two glass tubes, *a* and *b*, each of about 120 cubic centimetres capacity, joined together by means of the necks *d* and *f* connected by a piece of rubber tubing *x*.

The neck of *b* extends vertically, and has a stop cock *c* above the connection with *d*, and above this the tube is tapered and ground to form a seat for the funnel *m*. To the bottom of *a* is attached, by means of a rubber cork, a piece of glass tubing *i*, to which is attached a piece of rubber tubing, leading to the bottle *k*. To the bottom of *b* a similar attachment is made, the only difference being that in the tube *g* a two-way stop cock *h* is fitted.

One opening, shown at *s*, opens downwards, so that the contents of *b* can be emptied without passing into *l*. The other opening is directly through the cock, and connects *b* and *l*. *n* is a small barrel having a pipe and valve *o* for filling it with water, *q* a pipe and valve for emptying it, and *p*, a piece of gas piping with cock, the uses of which will be explained.

The method of using the apparatus and making the tests is as follows:

The top of the tube $b$ above $c$, is connected with the chimney whose gases are to be analyzed. The tubing connecting $g$ and $l$ is removed, and $g$ and $p$ are connected by means of tubing. The bottle, $k$, being filled with water, is raised until the water runs through $d$, $e$ being open, and fills $d$ to its connection with $b$. The cock $e$ is then closed, and $k$ is lowered to its original position.

The pipe $o$ is connected with a hydrant, $q$ is closed, the cock in $p$ is opened, $c$ is opened, and $h$ is put in such a position that $b$ and $n$ are in communication. Water is allowed to run from the hydrant until $n$, $b$ and the pipe connecting with the chimney are filled with water. $o$ is then closed, and $q$ is opened. The water flows back through $b$, and the chimney gas follows. After sufficient gas has been allowed to pass through $b$, the cocks $c$ and $h$ are closed.

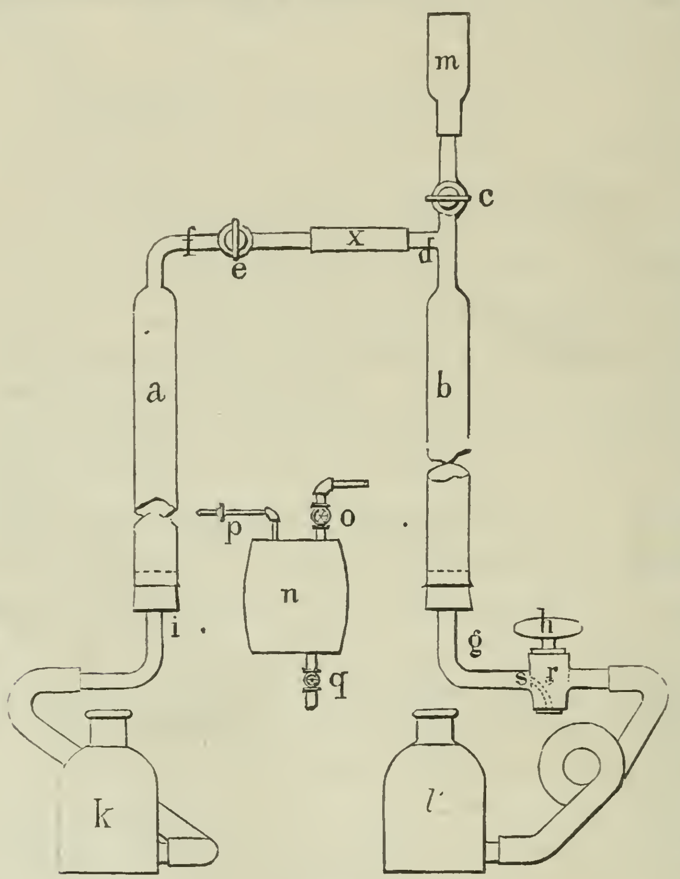



Fig. 5.

The tubing connecting $b$ and the chimney, and that connecting $q$ and $p$, are taken off, and the bottle $l$ is again attached to $g$.

A certain volume of the chimney gas is now confined in *b*, and the apparatus can be moved to any convenient place for further work. The cock *e* being closed, *c* and *h* are opened, and the water is allowed to flow back into *k* until a certain quantity, say 100 cubic centimetres, of the gas is in *a*. The cock *c* is closed and the gas allowed to assume the temperature of the air. The cock *h* is turned so that *b* can be washed out, *c* is opened and the funnel *m* put on; *b* is washed out and filled with clear water from *l*, the cock *h* being again turned and *c* being closed; *k* is now raised until the level of the water in *a* and *k* is the same, and the reading of the scale on *a* is noted.

In the apparatus used, the volume was divided into cubic centimetres, beginning at the cock *e*, but any division into equal volumes would do equally well, and it is not at all necessary that 100 cubic centimetres, or 100 equal parts, should be used in the calculations.

The volume in *a* being noted, the cock *e* is opened, *h* being already so, and the gas is passed back into *b*.

The cock *e* is closed. The funnel *m* is partly filled with caustic potash, the cock *h* is closed and the cock *c* is opened until the greater part of the caustic potash has passed into *b*; *c* is now closed, *e* is opened and the gas again passed into *a*, where its volume is again noted, the level of the liquid in *a* and *k* being the same. As the caustic potash has absorbed all the carbonic acid ($CO_2$) in the gas, the difference in readings already taken is the volume of carbonic acid in the gas. The The tube *b* is washed out and the process is repeated, using pyrogallic acid in caustic potash, and copper chloride in hydrochloric acid. The first of these removes the oxygen, and the last the carbonic oxide (CO).

To determine the amount of air present per pound of carbon, add together the volume of O and CO and twice the volume of $CO_2$. Divide by the sum of the volumes of CO and $CO_2$, and $\frac{4}{3}$ the quotient is the weight of oxygen present per pound of carbon. This result divided by ·23 is the weight of air used per pound of carbon, and this result divided by the percentage of carbon in the coal is the weight of air used per pound of coal.

## MAKING THE TESTS.

In making the boiler tests, steam was first raised to the working pressure in each boiler, and the fires were then hauled. All wood and

coal used thereafter was weighed, and at the end of the test the fire was hauled, and any unburnt coal credited to the boiler.

Water in the boiler was carried as nearly as possible at one height, and at the end of the test was brought back to the same level as at the beginning of the test.

DURATION OF THE TESTS.

Each test lasted 36 hours, except in the case of the Baldwin boiler, where the test was terminated at the end of 24 hours.

The following are the results of the different tests, together with the results derived from the observed data.

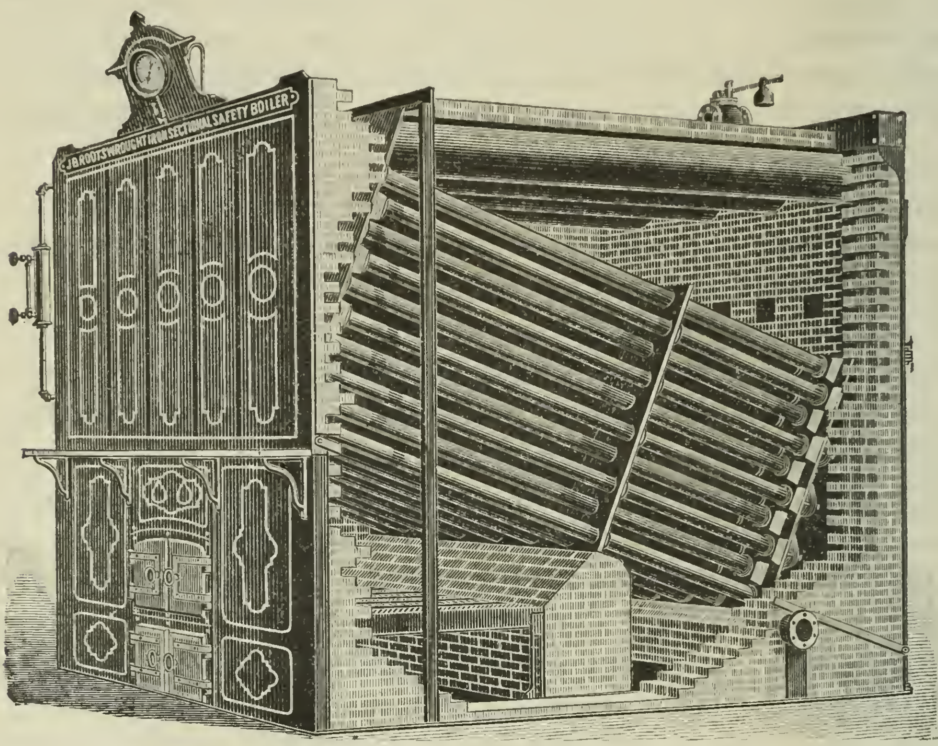



FIG. 6.

ROOT BOILER.

Before testing this boiler, (Fig. 6,) the back was boarded up. No other preparations were made for the test except cleaning the boiler the day before.

Ordinary care was taken with the fires, and the boiler was treated as in ordinary use.

Fires were started at 2.15 A.M., October 2, and as soon as the pressure of steam to be carried was reached, fires were hauled, and again

started at 3.25 A.M., with a weighed quantity of wood and coal. At 3.25 P.M., October 3, fires were hauled and the test concluded.

BOILER MADE BY ABENROTH & ROOT MANUFACTURING COMPANY.

| | | |
|---|---|---|
| Rated horse-power | | 150. |
| Area heating surface. | | |
| Having water on one side | = | 1440 square feet. |
| Having steam on one side | = | 360 square feet. |
| Total | = | 1800 square feet. |
| Area of grate | = | 50 square feet. |
| Steam space (approximate) | = | 76·5 cubic feet. |
| Height of smoke stack | = | 44 feet 6 inches. |
| Size of stack | = | 30 by 30 inches. |
| Time of test | = | 36 hours. |
| Water evaporated in boiler | = | 134937·3 pounds. |
| Mean temperature of feed water | = | 71·6 degrees F. |
| Total weight of wood used | = | 291·5 pounds. |
| Total weight of coal used | = | 18021·5 pounds. |
| Total weight of ashes | = | 2666·75 pounds. |
| Percentage of carbon in coal | = | 75·52. |
| Mean temperature of air during test | = | 57·0 degrees F. |
| Mean barometer | = | 30·323 inches. |
| Mean pressure in boiler | = | 91·41 pounds. |
| Mean temperature of steam | = | 341·32 degrees F. |
| Mean temperature of smoke stack | = | 369·92 degrees F. |
| Mean draft in chimney in inches of water | = | ·7. |
| Time during which blower was in use | = | 16 hours. |
| Mean pressure in boiler pipe | = | 1·16 inches. |
| Mean area of blower pipe open | = | 49·93 square inches. |
| Mean pounds of air per pound of carbon | = | 16·83. |

The quality of steam from the calorimeter tests has not been determined, as the want of agreement in the two sets of tests make the results unsatisfactory.

The following gives the number of heat units in one pound of steam by both the apparatus shown in Fig. 3, and by using the plain barrel, and I would recommend that these results be entirely rejected, and the quality of the steam taken as from the temperature, which would make in this case 9·37° superheating.

The following table is from the calorimeter tests:

| Time. | Total heat in 1 pound of steam from 32°F. | |
|---|---|---|
| | Apparatus of Fig. 3. | Barrel. |
| October 2, 2.57 P.M | 1335·4 | 1185·5 |
| " 3.57 " | 1323·2 | 1290·1 |
| " 4.57 " | 1306·7 | 1272·5 |
| " 5.57 " | 1309·7 | 1192·8 |
| " 7.57 " | 1406·3 | 1367·8 |
| " 9.57 " | 1247·0 | 1485·5 |
| " 11.57 " | 1270·5 | 1047·2 |
| October 3, 1.57 A.M | 1282·5 | 1396·8 |
| " 2.57 " | 1344·6 | 1003·2 |
| " 3.57 " | 1285·7 | 1142·8 |
| " 4.57 " | 1281·8 | 1343·3 |
| " 5 57 " | 1335·0 | 1205·1 |
| " 6.57 " | 1250·4 | 1093·2 |
| " 7.57 " | 1216·4 | 1158·1 |
| " 9.57 " | 1256·4 | 1329·7 |
| " 12.57 P.M | 1268·8 | 1179·9 |
| " 1.57 " | 1296·7 | 1206·0 |
| " 2.57 " | 1313·9 | 1177·3 |

Calling one pound of wood equal to ·24 pound of coal in heating effect, the total equivalent weight of coal used is 70 + 18021·5 = 18091·5 pounds.

The percentage of ash is 14·74, while as shown from the analysis made it is 14·52 per cent.

The heat giving power of the fuel is determined as follows: There being 75·52 per cent. of carbon, and 2·18 per cent. of hydrogen exclusive of water, the equivalent percentage of carbon is 75·52 + 4·28 × 2·18 = 84·85 per cent., and the amount of carbon equivalent to the 18091·5 pounds of coal is ·8485 × 18091·5 = 15350·64 pounds of carbon.

To change one pound of water at 71·6° F. to steam at 341·32° F. requires 1186·04 — 39·6 = 1146·44 heat units. As it takes 966·07 heat units to change one pound of water at 212° F. to steam at 212; one pound of water from 71·6° to one pound of steam at 341·32° requires the same amount of heat as 1·1867 pounds from and at 212°.

| | |
|---|---|
| Pounds of water evaporated per hour under the conditions ..... | = 3748·26 |
| Pounds of water evaporated per hour from and at 212° F.......... | = 4448·0 |
| Pounds of coal used per hour...... ...................... ......................... | = 468·87 |
| Equivalent pounds of carbon used per hour............................. | = 426·41 |
| Horse-power of boiler (on the basis of 30 pounds of water from and at 212° per horse-power) .................. ........................ | = 148·27 |
| Pounds of water evaporated per pound of coal under the conditions........................ .............................................. | = 7·9942 |
| Pounds of water evaporated per pound of coal from and at 212°.. | = 9·4866 |
| Pounds of water evaporated per equivalent pound of carbon under the conditions............................................ ........... | = 8·7903 |
| Pounds of water evaporated per equivalent pound of carbon from and at 212° F........................................................ | = 10·4313 |

Amount of air used in furnace per pound of coal $= \frac{16·83}{·7552} = 22·29$ pounds.

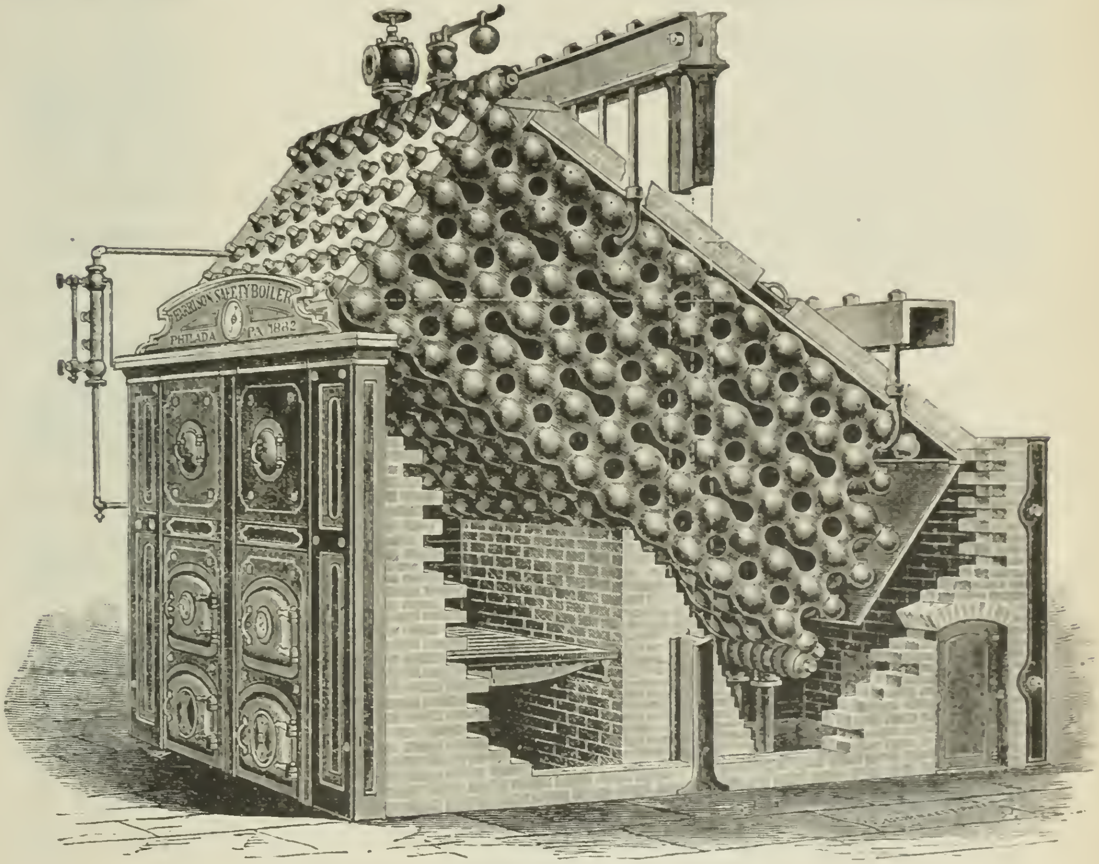



FIG. 7.

HARRISON BOILER.

The test began at 11.25 A. M., October 9, 1884, in the same manner as described for the Root test. At 12.57 P. M., October 10, cleaned boiler by means of steam nozzle, and at 11.25 P. M., October 10, fires were hauled and the test concluded.

| | |
|---|---|
| Rating of boilers, manufacturers | 100 horse-power |
| Water heating surface | 948·54 sq. feet. |
| Steam " " | 348·96 " |
| Total " " | 1297·50 " |
| Steam room in boiler | 29·8 cubic feet. |
| Grate surface | 35·13 sq. feet. |
| Height of stack from ground | 44 feet 6 in. |
| Size of pipe | 30 × 30. |
| Water in boiler to steaming level | 4878 pounds. |
| Time of test | 36 hours. |
| Total weight of water evaporated in boiler | 92606·75 pounds. |
| Mean temperature of water | 68·77° F. |
| Total weight of wood used | 348·5 pounds. |
| " " coal " | 11725·75 " |
| " " ashes | 1475·75 " |
| Percentage of carbon in coal | 75·21 |
| " " hydrogen " | 1·82 |
| Mean temperature of air during test | 57·84° F. |
| Mean barometer | 30·253 inches. |
| Mean pressure in boiler | 95·83 pounds. |
| Mean temperature of steam | 337·16° F. |
| Mean temperature of smoke-pipe | 411·03° F. |
| Mean draft in chimney | ·24 in. water. |

Mean pounds of air per pound of carbon = 15·09.

## QUALITY OF STEAM.

The quality of the steam was determined both by the Barrus calorimeter and the apparatus shown in Fig. 3, with the following results:

### BARRUS CALORIMETER.

| | | | | |
|---|---|---|---|---|
| From 5.40 P. M. to 7.40 P. M., October 9 | steam contains | 7·4 | per ct. | water. |
| From 7.40 P. M. to 9.40 P. M., October 9 | " " | 7·0 | " | " |
| From 9.40 P. M. to 11.40 P. M., October 9 | " superheated 63° | | | |
| From 1.25 A. M. to 4.20 A. M., October 10 | steam contains | 3·4 | per ct. | water. |
| From 4.20 A. M. to 11.30 A. M., October 10 | " " | 3·5 | " | " |
| From 11.30 A. M. to 1.25 P. M., October 10 | " " | 2·1 | " | " |
| From 2.40 P. M. to 4.45 P. M., October 10 | " " | 0·11 | " | " |
| From 4.50 P. M. to 6.45 P. M., October 10 | " " | 2·8 | " | " |
| From 6.50 P. M. to 8.55 P. M., October 10 | " " | 4·5 | " | " |
| From 9.45 P. M. to 11.20 P. M., October 10 | " superheated 168°. | | | |

From the apparatus shown in Fig. 3, we have the following results:

| | |
|---|---|
| 1.00 P. M., October 9 | steam superheated 68°. |
| 2.00 P. M., October 9 (a) | " " beyond limits of tables. |
| 4.00 P. M., October 9 | " contains 13·1 per cent. water. |
| 5.00 P. M., October 9 | " " 5·3 " " |
| 6.00, 9.00, 10.00, 11.00, 12.00 | same as (a). |

7.00 .......................................... steam contains 30·7 per cent. water.
1.00 A. M., October 10.......................... same as (a).
3.00 A. M., October 10.......................... steam superheated 57°.
5.00, 6.00 A. M., October 10.................... same as (a).
7.00 A. M., October 10.......................... steam contains 7·7 per cent. water.
8.00 A. M., October 10.......................... " superheated 57°.
9.00, 10.00, 11.00, 12.00, October 10. ......... same as (a).
1.00 P. M., October 10.......................... same as (a).
3.00, 4.00, 5.00, 6.00, October 10.............. same as (a).
7.00 P. M., October 10.......................... steam superheated 70°.
9.00, 10.00 and 11.00 P. M., October 10......... same as (a).

While the results given from the Barrus calorimeter show a reasonable agreement, it is doubtful whether the results are a fair measure of the quality of the steam produced, as the thermometer in the steam space shows 337·16° F., while the temperature corresponding to the steam pressure 95·83 pounds is 334·93° F. The difference, or 2·23°, shows that the average quality of the steam was dry or superheated 2·23° F., and in the succeeding deductions this value will be taken in calculating the relative weight of water evaporated per pound of coal.

As before, assuming that one pound of wood = ·24 pounds of coal, the total equivalent weight of coal used is $348·5 \times ·24 + 11725·75 =$ $11809·39$ pounds. The percentage of ash is $\frac{1475·75}{11809·39} = 12·5$ per cent., while the analysis made shows 14·03 per cent.

The heat giving power of the fuel is determined as follows: there being 75·21 per cent. of carbon and 1·82 per cent. of hydrogen, exclusive of water, the equivalent percentage of carbon is $75·21 + 1·82 \times 4·28 =$ 83·00 per cent., and the equivalent amount of carbon in the 11809·39 pounds of coal is $11809·39 \times ·83 = 9801·79$ pounds.

To change one pound of water at 68·77° F. into steam at 337·16° F. requires $1184·77 - 36·77 = 1148·00$ heat units. As it takes 966·07 heat units to change one pound of water at 212° into steam, at 212°, one pound of water from 68·77° to steam at 337·16° requires the same amount of heat as 1·1883 pounds of water from and at 212°.

| | |
|---|---|
| Pounds of water evaporated per hour under the conditions....... | = 2572·41 |
| Pounds of water evaporated per hour from and at 212°.............. | = 3056·79 |
| Pounds of coal used per hour.............................................. | = 328·04 |
| Equivalent pounds of carbon used per hour.............................. | = 272·27 |
| Horse-power of boiler on the basis of 30 pounds of water from and at 212° per horse-power.............................................. | = 101·89 |

Pounds of water evaporated per pound of coal under the conditions .................................................................... = 7·8417
Pounds of water evaporated per pound of coal from and at 212°.. = 9·3183
Pounds of water evaporated per equivalent pound of carbon under the conditions ................................................ ... = 9·4480
Pounds of water evaporated per equivalent pound of carbon from and at 212°.. .................................................. = 11·2270

Amount of air used in furnace per pound of coal $\frac{15·09}{·7521} = 20·06$ pounds.

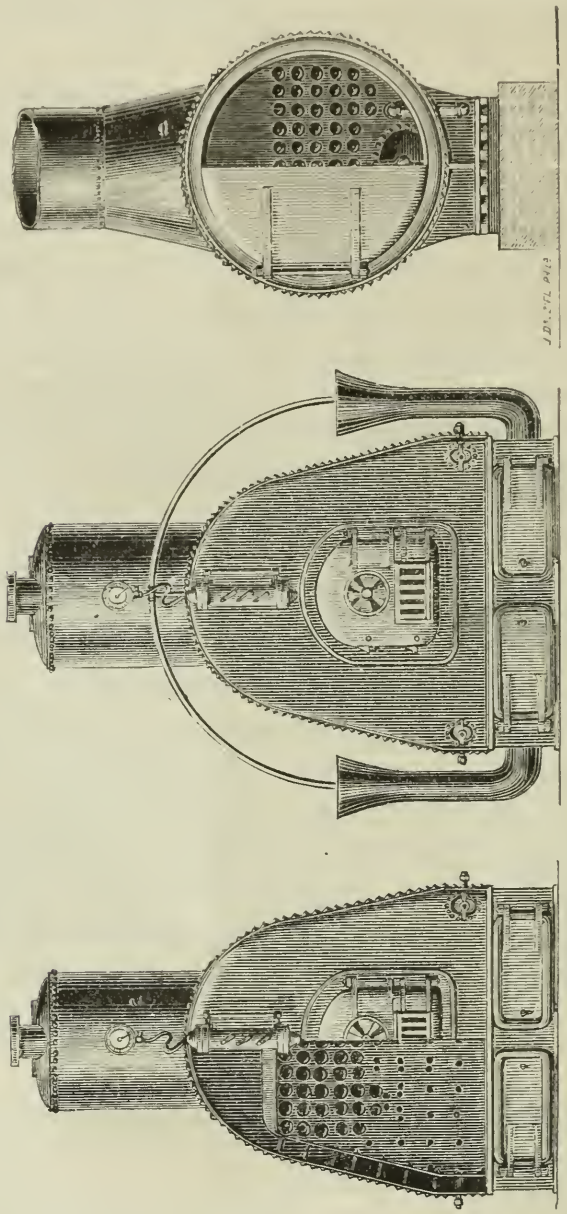


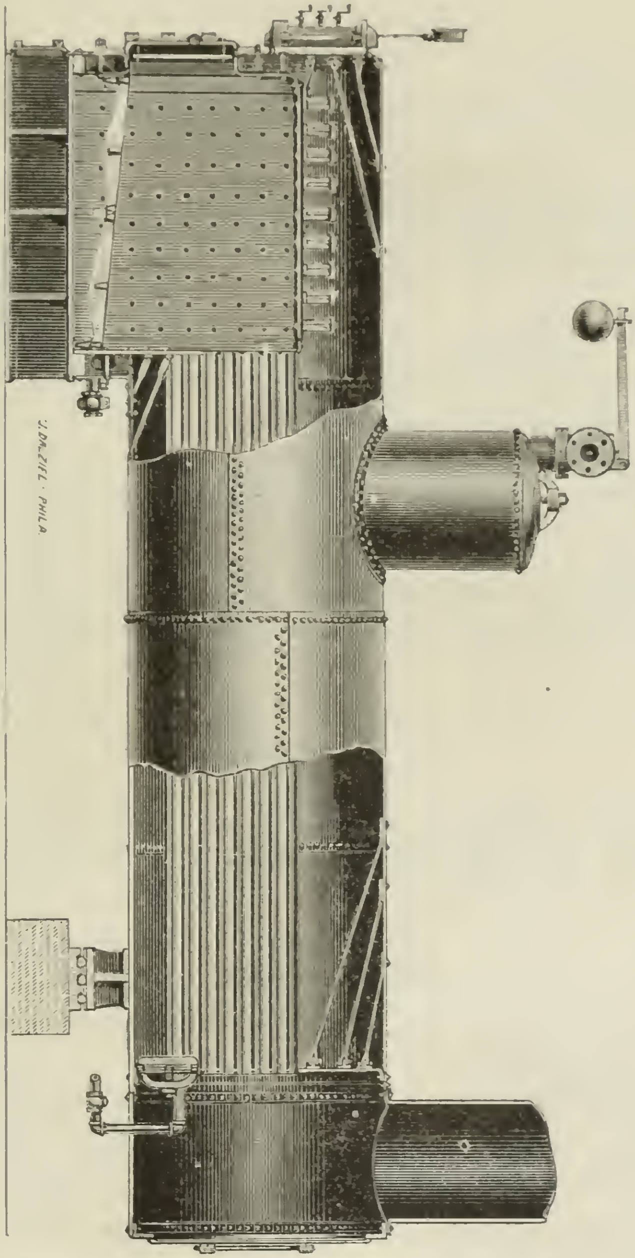
FIG. 8.

DICKSON BOILER.

This boiler, Figs. 8 and 9, is manufactured by the Dickson Manu-

facturing Company, of Scranton, Pennsylvania. It is a horizontal tubular boiler having 68, 3 inch tubes, each 15 feet long. It has a spread fire box wider at the top than at the bottom. The grate used was of the Howe pattern, 6 feet 6 inches by 4 feet 10 inches. The shell is cylindrical 50 inches in diameter and is 34½ feet long. The steam dome is 30 inches by 30 inches.

FIG. 9.




Rating of boiler, manufacturers = 76 horse-power. Before beginning this test the boiler was thoroughly protected by means of a one-inch layer of felt over the entire boiler, excepting the front head. The

test began at 6.31 P. M., October 13, 1884, and ended at 6.31 A. M., October 15.

The boiler was designed to burn culm, but as none could be procured in time for the test, screenings from pea coal were used instead.

| | | |
|---|---|---|
| Water heating surface | = | 841· sq. feet. |
| Steam " " | = | 2·5 " |
| Total " " | = | 843·5 " |
| Grate surface | = | 31·41 " |
| Steam space in boiler | = | 67 cubic ft. |
| Weight of water in boiler at ordinary standing level | = | 10200 pounds. |
| Time of test | = | 36 hours. |
| Total weight of water evaporated in boilers | = | 137152·75 pounds. |
| Water used per hour to run jet | = | 472·5 " |
| Mean temperature of water | = | 67·17° F. |
| Total weight of wood used | = | 232·5 pounds. |
| " " coal " | = | 20026·50 " |
| " " ashes (net) | = | 5048·37 " |
| Percentage of carbon in the coal | = | 72·87 |
| " hydrogen (exclusive of water) | = | 2·53 |
| Mean temperature of air | = | 50·26° F. |
| Mean barometer | = | 30·299 inches. |
| Mean pressure in boiler | = | 83·54 pounds. |
| Mean temperature of steam | = | 326·19° F. |
| Mean temperature of smoke-stack | = | 422·72° F. |
| Mean draft in chimney | = | ·15 inches. |
| Mean air per pound of carbon | = | 13·66 pounds. |

## QUALITY OF STEAM.

The quality of the steam was determined both by the Barrus calorimeter and by the apparatus shown in Fig. 3, with the following results:

### BARRUS CALORIMETER.

From 7.20 P. M., October 13 to 11.20 A. M., October 14, steam contains 0·78 per cent. water.

From 1.20 A. M. to 3.20 A. M., October 14, steam contains 2·7 per cent. water.

From 3.20 A. M. to 5.20 A. M., October 14, steam contains 1·9 per cent. water.

From 5.20 A. M. to 12.00 noon, October 14, steam contains 2·5 per cent. water.

From 12.00 noon to 2.00 P. M., October 14, steam contains 7·6 per cent. water.

From 2.00 P. M. to 4.00 P. M., October 14, steam superheated 22°.

From 4.00 P. M. to 6.00 P. M., October 14, steam superheated 7°.

From 6.00 P. M. to 8.00 P. M., October 14, steam contains 1·2 per cent. water.

From 8.00 P. M. to 10.00 P. M., October 14, steam contains 3·8 per cent. water.

From 10.00 P. M. to 12.00 midnight, October 14, steam contains 2·6 per cent. water.

From 10.00 midnight to 2.00 A. M., October 15, steam contains 0·8 per cent. water.

From 2.00 A. M., October 15 to 4.00 A. M., October 15, steam contains 1·7 per cent. water.

From 4.00 A. M., October 15 to 6.00 A. M., October 15, steam contains 1·2 per cent. of water.

The results from the apparatus shown in Fig. 3 were totally unreliable, giving in every case highly superheated steam of 400° or over.

As the temperature of the steam almost exactly corresponds with the temperature corresponding to the pressure, it is evident that the steam must have been either saturated or wet, and taking the results from the Barrus apparatus as correct, we have for a mean 1·55 per cent. of moisture in the steam, and this value will be taken in the succeeding deductions.

As before, assuming that one pound of wood = ·24 pounds of coal, the total equivalent weight of coal used is $232·5 \times ·24 + 20026·50 = 20082·3$ pounds.

The percentage of ash is $\frac{5048·37}{20082·3} = 25·1$ per cent., while the analysis of the coal made shows but 10·39 per cent. This discrepancy may be accounted for in the following way: the coal used was siftings from pea coal, considerable of which fell through the grate partly burned, and as the ashes were continually wet from the steam jet, no attempt was made to burn the refuse a second time, as the loss from the wet ashes would probably be more than the gain from more perfect combustion.

The equivalent weight of carbon used was determined as in the case of the preceding boilers. The percentage of carbon being 72·87 and of hydrogen (exclusive of water) 2·53, the equivalent percentage of carbon is $72·87 + 4·28 \times 2·53 = 83·70$; and the equivalent amount of carbon in the 20082·3 pounds of coal is 16808·89 pounds.

To change one pound of water at 67·17° into steam 83·54 pounds pressure and containing 1·55 per cent. of moisture requires 1167·78

— 35·17 = 1132·61 heat units. As it takes 966·07 heat units to change one pound of water at 212° into dry steam at 212°, one pound of water under the conditions of this test requires the same amount of heat as 1·1724 pounds of water from and at 212°.

As the total weight of water evaporated is 137152·75 pounds, and as 472·5 pounds of water are used per hour to run the jet, the amount of water available for use outside the boiler, or the proper quantity of water which should be credited to the boiler is 137152·75 — 36 × 472·5 = 135451·75 pounds.

| | |
|---|---|
| Pounds of water evaporated per hour under the conditions | = 3762·55 |
| Pounds of water evaporated per hour from and at 212° | = 4411·21 |
| Pounds of coal used per hour | = 557·84 |
| Equivalent pounds of carbon used per hour | = 466·91 |
| Horse-power of boiler (on basis of 30 pounds of water from and at 212° per horse-power) | = 147·04 |
| Pounds of water evaporated per pound of coal under the conditions | = 6.7449 |
| Pounds of water evaporated per pound of coal from and at 212° | = 7·9076 |
| Pounds of water evaporated per equivalent pound of carbon, under the conditions | = 8·0584 |
| Pounds of water evaporated per equivalent pound of carbon from and at 212° | = 9·4477 |

Amount of air used in furnace per pound of coal $= \frac{13·66}{·7287} =$ 18·74 pounds.

## BALDWIN BOILER.

An attempt to test this boiler was made on September 29, 1884, and after continuing for 24 hours, the fires became very low because of the coal having so much clinker, requiring that the fires should be constantly cleaned, and the test was stopped.

At the request of the company exhibiting the boiler, a second test was made beginning at 1.19 P. M., October 24, 1884, and ending at 1.19 P. M., October 25, 1884, and the results of this test alone are given in this report.

This boiler was made by the Baldwin locomotive works. It is a horizontal cylindrical flue boiler, sixteen feet long, of 54 inches diameter, and having 4-inch flues. The bottom of the boiler was set 34 inches above the grate.

Over the boiler is placed a steam drum twenty-four inches in diameter and eight feet long, connected to the boiler by means of one neck 12 inches in diameter and 10 inches long.

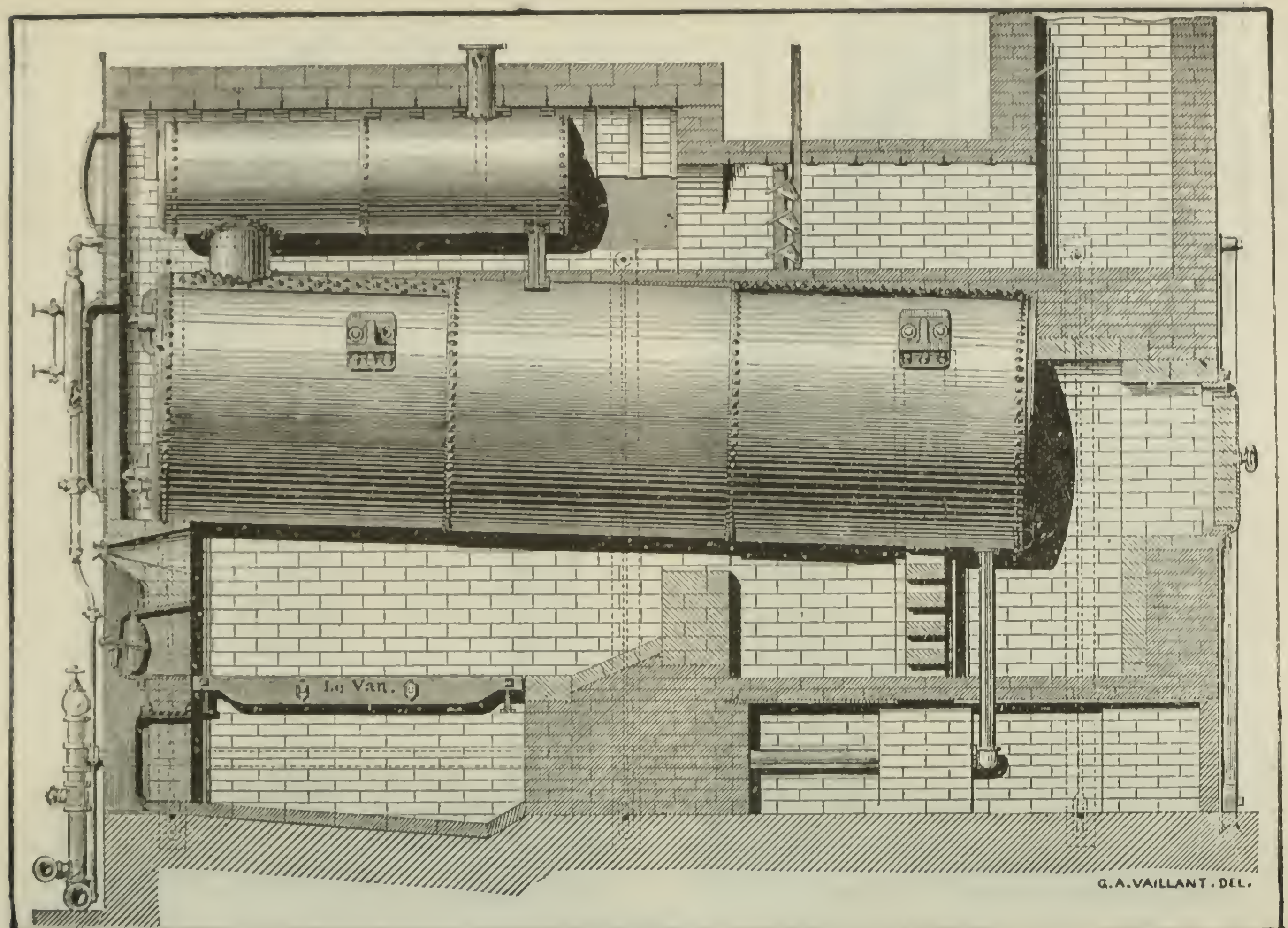



FIG. 10.

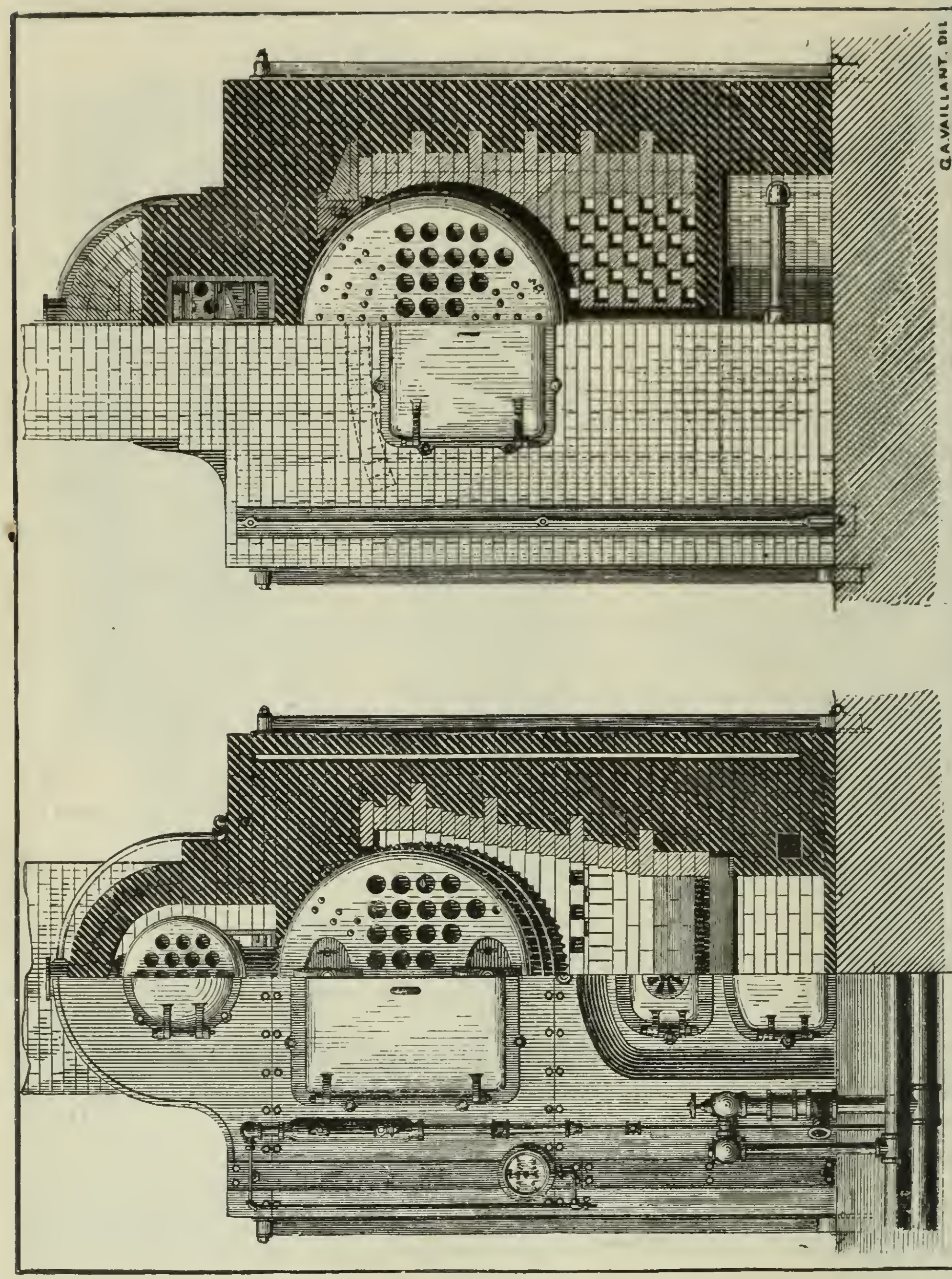



FIG. 11.

| | | |
|---|---|---|
| Rating of boiler | | 50 horse-power. |
| Grate surface | | 21 square feet. |
| Heating surface, total | | 799·62 sq. feet. |
| " " wetted | = | 663·31 sq. feet. |
| " " steam | = | 136·31 sq. feet. |
| Grate 42 inches by 72 inches. | | |
| Chimney 30 inches by 30 inches. | | |
| Height of chimney | | 44 feet 6 inches. |
| Time of test | | 24 hours. |
| Total weight of water evaporated in boiler | = | 38108·0 pounds. |
| Mean temperature of water | = | 59·91° F. |
| Total weight of wood used | = | 191·5 pounds. |
| Total weight of coal used | = | 6031·0 " |
| Total weight of ashes | = | 654·25 " |
| Percentage of carbon in coal | | 80·22 |
| Percentage of hydrogen (exclusive of water) | = | 2·53 |
| Mean temperature of air during test | = | 45·25° F. |
| Mean barometer | = | 30 274 inches. |
| Mean pressure in boiler | = | 98·71 pounds. |
| Mean temperature of steam | = | 343·78° F. |
| Mean temperature of smoke stack | = | 346·85° F. |
| Mean draft in chimney | = | ·243 inches. |
| Mean air per pound of carbon | = | 16·24 pounds. |

QUALITY OF STEAM.

The quality of the steam was determined only by the Barrus calorimeter with the following results:

From 2.50 P. M., October 24, to 4.20 P. M. October 24, steam contains 0·78 per cent. water.

From 4.20 P. M., October 24, to 6.20 P. M., October 24, steam contains 1·8 per cent. water.

From 6.20 P. M., October 24, to 8.20 P. M., October 24, steam contains 1·9 per cent. water.

From 8.20 P. M., October 24, to 10.20 P. M., October 24, steam is dry.

From 10.20 P. M., October 24, to 12.20 A. M., October 25, steam contains 2·8 per cent. water.

From 2.20 A. M., October 25, to 4.20 A. M., October 25, superheated 174°.

From 4.20 A. M., October 25, to 6.20 A. M., October 25, contains 3·9 per cent. water.

From 8.40 A. M., October 25, to 12.20 P. M., October 25, contains 23.5 per cent. water.

The mean of these results is 6·95 per cent. of moisture in the steam. The temperature of the steam by thermometer is 343·78° F., and the temperature corresponding to the pressure 98·71 pounds per gauge is 336·83° F., and the average quality of the steam from the temperature

is 6·95° superheated. Assuming that this latter value is more correct than the one given by the Barrus calorimeter, this value will be used in the following deductions.

As before, assuming that one pound of wood = ·24 pounds of coal, the total equivalent weight of coal used is 6031 + 191·5 × ·24 = 6076·96 pounds.

The percentage of ash is $\frac{654.25}{6076{\cdot}96} = 10{\cdot}76$ per cent., while the analysis made shows 10·39 per cent.

The equivalent weight of carbon used was determined as in the cases of the preceding boilers. The percentage of carbon being 80·22, and of hydrogen (exclusive of water) 2·53 per cent, the equivalent percentage of carbon is 80·22 + 4·28 × 2·53 = 91·05 per cent., and the equivalent amount of carbon in 6076·96 pounds of coal is = 5533·07 pounds.

To change one pound of water at 59·91° into steam of 98·71 pounds pressure and 6·95° superheated, requires 1186·791 — 27·91 = 1158·881 heat units. As it takes 966·07 heat units to change one pound of water at 212° into steam at 212°, one pound of water under the conditions of this test requires the same amount of heat as 1·1996 pounds of water from and at 212°.

| | |
|---|---|
| Pounds of water evaporated per hour, under the conditions...... = | 1587·83 |
| Pounds of water evaporated per hour, from and at 212°............ = | 1904·76 |
| Pounds of coal used per hour............................................... = | 253·21 |
| Equivalent pounds of carbon used per hour.............................. = | 230·54 |
| Horse-power of the boiler (on the basis of 30 pounds of water from and at 212° per hour, horse-power)............................ = | 63·49 |
| Pounds of water evaporated per pound of coal, under the conditions.................................................................. = | 6·2708 |
| Pounds of water evaporated per pound of coal from and at 212° = | 7·5224 |
| Pounds of water evaporated per equivalent pound of carbon, under the conditions................................................... = | 6·8874 |
| Pounds of water evaporated per equivalent pound of carbon, from and at 212°.............................................................. = | 8·2621 |
| Amount of air used in the furnace per pound of coal................ = | 20.24 lbs. |

*Resumé of Results obtained in Boiler Tests.*

| Name of Boiler on Trial. | Root. | Harrison. | Dickson. | Baldwin. |
|---|---|---|---|---|
| Date of Trial. | Oct. 2, 1884. | Oct. 9. | Oct. 13. | Oct. 24. |
| Duration of trial in hours | 36 | 36 | 36 | 24 |
| Rated horse-power by makers | 150 | 100 | 76 | 50 |
| Developed horse-power in test assuming 30 pounds of water from and at 212 degrees per horse-power | 148·27 | 101·89 | 147·04 | 63·19 |
| Water heating surface in square feet | 1440 | 948·54 | 841 | 663·31 |
| Steam heating surface in square feet | 360 | 348·96 | 2·50 | 136·31 |
| Total heating surface in square feet | 1800 | 1297·5 | 843·50 | 799·62 |
| Grate surface in square feet | 50 | 35·13 | 31·41 | 21 |
| Ratio of grate to heating surface | 1 : 36 | 1 : 37 | 1 : 26·8 | 1 : 38 |
| Height of chimney, in feet, from grate | 44·5 | 44·5 | 28·6 | 44·5 |
| Average steam pressure in pounds per square inch | 91·41 | 95·83 | 83·54 | 98·71 |
| Barometer in inches | 30·323 | 30·253 | 30·299 | 30·274 |
| TEMPERATURES, FAHRENHEIT. | | | | |
| Average temperature of the air (Fah.) | 57 | 57·84 | 50·26 | 45·25 |
| Average temp. of the steam in boilers | 341·32 | 337·16 | 326·19 | 313·78 |
| Temperature corresponding to average boiler pressure | 331·95 | 334·93 | 326·36 | 336·83 |
| Average temperature of the chimney | 369·92 | 411·03 | 422·72 | 346·85 |
| Average temperature of the feed-water | 71·6 | 68·77 | 67·17 | 59·91 |

*Resumé of Results obtained in Boiler Tests.—Continued.*

| Name of Boiler on Trial. | Root. | Harrison. | Dickson. | Baldwin |
|---|---|---|---|---|
| Date of Trial. | Oct. 2, 1884, | Oct. 9. | Oct. 13. | Oct. 21. |
| COAL AND ASHES. | | | | |
| Pounds of wood used | 291·5 | 348·5 | 232·5 | 191·5 |
| Pounds of coal used | 18021·5 | 11725·75 | 20026·5 | 6031 |
| Pounds of coal and wood, including value of latter | 18091·5 | 11809·39 | 20082·3 | 6076·96 |
| Pounds of ashes | 2666·75 | 1475·75 | 5048·37 | 654·25 |
| Pounds of carbon | 15350·64 | 9801·79 | 16808·8 | 5533·07 |
| Pounds of carbon per hour | 426·41 | 272·27 | 466·9 | 230·54 |
| Pounds of coal per hour | 468·87 | 328·04 | 557·84 | 253·21 |
| WATER. | | | | |
| Pounds of water feed in the boiler at average temperature above given | 134937·3 | 92606·75 | 137152·75 | 38108 |
| Pounds of water evaporated per hour from and at 212° | 4448 | 3056·79 | 4411·21 | 1587·83 |
| Pounds of water evaporated per pound of coal | 7·99 | 7·84 | 6·75 | 6·27 |
| Pounds of water evaporated per pound of carbon from and at 212° | 10·43 | 11·23 | 9·45 | 8·26 |
| Quality of steam by thermometer, or amount of superheating | 9·37 | 2·23 | ............ | 6·95 |
| Percentage of moisture | ............ | ............ | 1·55 | ............ |
| RATE OF COMBUSTION. | | | | |
| Pounds of coal burnt per square foot of grate per hour | 10 | 9·3 | 18 | 12 |
| Pounds of water per square foot of grate per hour | 87 | 89 | 140 | 76 |
| Pounds of water per square foot of heating surface per hour | 2·3 | 2·5 | 5.2 | 2 |
| DRAFT. | Blower. | Natural. | Steam Jet. | Natural. |
| Mean draft in chimney in inches | 0·7 | ·24 | ·15 | .43 |
| Steam room in boiler in cubic feet | 7·65 ap. | 29·8 | 67 | ............ |

At the meeting of the Examiners of Section X, held at the Franklin Institute, March 23, 1885, the following resolution was adopted: *

*Resolved*, That the report of Mr. Spangler be adopted as rendered, and that the same be published in its entirety, with the addition of a tabulated resumé of the results. That the committee refrain from criticism of the boilers as prescribed by the Code, excepting upon the points of economy of fuel and evaporated efficiency, as contained in report adopted. That all accuracy of the calorimetrical measurements be disclaimed, but all data referring thereto be printed, as evidence of work performed in the attempt to obtain reliable results.

| | |
|---|---|
| WM. D. MARKS, | ARTHUR L. CHURCH, |
| W. BARNET LE VAN, | FRED'K GRAFF, |
| C. CHABOT, | CHAS. E. RONALDSON, |
| A. B. WYCKOFF. | OTTO C. WOLF, |
| | *Committee present.* |

*Members of Section X.*—Gould H. Bull, C. Chabot, R. E. Crawford, J. E. Denton, Charles H. Fisher, Carl Hering, Washington Jones, Gaetano Lanza, W. Barnet Le Van, William Ludlow, William D. Marks, O. E. Michaelis, John Milliss, John W. Nystrom, T. W. Rae, Charles E. Ronaldson, H. W. Spangler, Otto C. Wolf, A. B. Wyckoff.

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* This report has, according to the directions of the Board of Managers of the Franklin Institute, been edited and supervised by the Committee appointed for that purpose. The language of this resolution must not be interpreted to imply that any exception was made to the mode of printing the reports.

PERSIFOR FRAZER,
WM. H. WAHL,
*Executive Committee of Editing Committee.*

FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA,

FOR THE

PROMOTION OF THE MECHANIC ARTS

---

ON THE

# EFFICIENCY AND DURATION

—OF—

# Incandescent Electric Lamps.

---

Report of a Special Committee, appointed by the President of the Franklin Institute, in conformity with a Resolution of the Board of Managers, passed November 12, 1885.

[ISSUED BY AUTHORITY OF THE BOARD OF MANAGERS AND PUBLISHED AS A SUPPLEMENT TO THE JOURNAL OF THE FRANKLIN INSTITUTE, SEPTEMBER, 1885.]

PHILADELPHIA:
THE FRANKLIN INSTITUTE.
1885

## EDITING COMMITTEE.

PERSIFOR FRAZER, *Chairman.*
CHARLES BULLOCK,
THEO. D. RAND,
COLEMAN SELLERS,
WILLIAM H. WAHL.

FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA.
FOR THE PROMOTION OF MECHANIC ARTS.

---

*To the Board of Managers of the Franklin Institute:*

GENTLEMEN:—I herewith transmit the report of the Committee, consisting of J. B. Murdoch, Lieut. U. S. Navy; Louis Duncan, Ph.D., Ensign U. S. Navy; William D. Marks, Whitney Professor of Dynamic Engineering, University of Pennsylvania; George M. Ward, M.D., Photometric Expert of the Trustees of the Philadelphia Gas Works, appointed under authority of the resolution of the Board, adopted November 12, 1884, to conduct examinations and tests of the efficiency and life duration of incandescent lamps.

I believe that the examination has been more thorough and that the report is more complete than anything that has hitherto appeared on the subject; and the INSTITUTE is deeply indebted to the members of the Committee for their faithful, zealous, and intelligent discharge of their protracted duties.

Very respectfully,

W. P. TATHAM,

*President.*

PHILADELPHIA, JULY 8, 1885.

[RESOLUTION OF THE BOARD OF MANAGERS. NOV. 12, 1884.]

WHEREAS, Through delay and lack of time on the part of many of the Examiners, several of the largest exhibits at the Electrical Exhibition have had either incomplete examination or have had none at all; therefore be it

*Resolved*, That the President be directed to take such steps, appoint such committees, and incur such expense, not exceeding three thousand dollars, as shall be necessary to complete in a satisfactory manner the examination of exhibits.

---

Mr. W. P. TATHAM,

*President of the Franklin Institute.*

SIR:—I have the honor to herewith transmit the report of the Committee on the Duration Test of Incandescent Lamps, conducted under the auspices of the FRANKLIN INSTITUTE.

I am, very respectfully yours,

J. B. MURDOCK.

PHILADELPHIA, July 8, 1885.

## DURATION TEST OF INCANDESCENT LAMPS.

The scheme for a duration or life test of incandescent lamps was organized during the Electrical Exhibition by the Executive Committee. It had been recognized that tests of incandescent lamps for the determination of the efficiency alone afforded no data for deciding upon their relative value, the lifetime of the lamp being an important factor in the question of economy. A test which should furnish information on this point would be very valuable. Plans were early made for such a test, but as the time required was such that it could not be conducted by the Photometric Group of the Board of Examiners, it was placed in charge of a special committee, and invitations were extended to the principal incandescent light companies to enter their lamps. Before the necessary arrangements could be completed several of the members of the special committee were compelled by their engagements to leave Philadelphia.

The Board of Managers of the FRANKLIN INSTITUTE thereupon placed the conduct of the tests in the hands of its president, who filled the vacancies existing in the committee, and authorized preparations for conducting the test on a larger scale than was possible during the continuance of the Electrical Exhibition. Three rooms in the exhibition building were set apart for the test.

A code had been prepared, specifying how the test should be conducted. This code was signed in December by Mr. Weston and Mr. Upton, representing the interests of the United States and the Edison companies. The Brush-Swan and the Bernstein companies declined to enter their lamps. The FRANKLIN INSTITUTE entered a lot of Woodhouse & Rawson lamps, obtained from the Van de Poele Company, and also two grades of the Stanley-Thompson lamp, made by the Union Switch and Signal Company, of Pittsburg. The president of the FRANKLIN INSTITUTE subsequently entered, for efficiency measurements, and for such a test of duration as circumstances would permit, a lot of Weston lamps (paper carbon), furnished by Mr. Weston; a lot of Woodhouse & Rawson lamps, received from the Edison Lamp Company, and a lot of White lamps, from the Electrical Supply Company.

In order to secure satisfactory results, and prevent needless discussion, the following code was agreed upon for the conduct of the test:

*Proposed Code for Duration Test of Incandescent Lamps to be made by the* FRANKLIN INSTITUTE *of the State of Pennsylvania.*

The parties hereto subscribing do agree to accept the services of the Examiners herein named, and to abide by the method adopted for the test, and by the results obtained, without appeal.

NAMES OF EXAMINERS.

| | |
|---|---|
| Lieut. J. B. MURDOCK, U. S. N. | Ensign L. DUNCAN, U. S. N. |
| Prof. WM. D. MARKS. | Dr. G. M. WARD. |

Each company to enter twenty lamps. The Examiners will select fifty lamps from a supply furnished by the companies, of not less than one hundred lamps. Twenty of these will be used in the preliminary adjustment of the circuit, and then replaced at the beginning of the test by twenty similar ones, until then unused, save for preliminary determinations.

A preliminary test of each lamp under normal conditions will be made before the beginning of the continuous test, and the time used will be credited to each lamp.

This preliminary test will determine the spherical intensity of the illumination and the reduction factor.

The FRANKLIN INSTITUTE shall have the right to enter lamps of different kinds for the test, such lamps to be treated in all respects as though entered by a competing company.

The difference of potential between the mains will be kept at 120 commercial volts. Weston's incandescent automatic regulator will be used, and no other adjustment of the potential of the mains will be attempted, save in the case of wide variation. A volt meter will be kept in circuit all the time.

A resistance of German-silver wire will be placed in circuit with each lamp, and a preliminary adjustment made, to give the lamp its proper difference of potential.

Exhibitors will give the potential required by their lamps. Unless the lamps are separately marked, all lamps of the exhibitor will be considered as exactly similar.

An Edison "T" dynamo, driven by a Porter-Allen engine, will be used. The circuit will be opened occasionally and the lamps allowed to cool.

Lamps shall be considered as out of the test when they fail to burn, whether due to breaking of glass or filament. When a lamp gives out, it will be replaced by one requiring subtantially the same difference of potential. The first three lamps of each company which are broken shall be replaced by others for which the preliminary measurements have been made, to be used only in case of accidental breakage.

The test may be declared ended at any time when in the opinion of the committee one system is so far in advance that a longer test could not change the result.

## MEASUREMENTS.

Measurements of currents, difference of potential between terminals of lamp, and photometric intensity, will be made. The lamps will be arranged in a circle, having the photometer bar for a radius, and will be placed with the plane of the loop perpendicular to the bar. All measurements will be reduced to mean spherical intensity, by multiplying the intensity measured, by a reduction factor determined for each lamp. Photometric measurements will be made as necessary, but not oftener than once daily.

Electric measurements will be made daily.

A record will be kept of each lamp, in which all data relating to it will be entered.

Weekly reports will be made to the FRANKLIN INSTITUTE of the observations made, and showing how long each lamp has been under test.

## METHODS.

The legal ohm will be considered the standard of resistance. The ampére will be determined by the silver voltameter, and checked by calculation of the constant of the current galvanometer used. The volt will be taken as that E. M. F. which produces a current of one ampére in a resistance of one legal ohm. The ampére equivalent of silver as determined by Lord Rayleigh will be accepted as correct.

Currents will be measured by a tangent galvanometer, the constant of which will be determined by the silver voltameter, and checked by calculation.

A standard resistance of German-silver wire wound on a reel will be carefully measured in turpentine or neutral oil, the temperature being observed. The potential galvanometer may be calibrated by connecting to the terminals of this resistance while a current simultaneously measured is passing through it. The temperature of the liquid will be observed and the resistance corrected therefor.

Calibrations will be made frequently during the test.

Potential may be measured by a mirror galvanometer in a shunt circuit of high resistance.

Each company will be permitted to have one authorized representative in attendance throughout the test, and every facility will be given to those representatives to inspect the working of the test that will not interfere with its progress.

The FRANKLIN INSTITUTE agrees to keep the lamps under proper surveillance, and to take necessary precautions for their safety. Lamps accidentally broken will not be charged against the companies.

The right is reserved to discontinue the test at such times and for such periods as may seem advisable or necessary.

A preliminary test will be made before the actual test begins, to insure good working.

In case any objection be made, or difference of opinion should arise between the committee and the contestants, the unanimous vote of the committee shall be final.

If, however, there be not a unanimous vote, the minority of the committee shall appoint one referee and the majority another; these two shall appoint a third referee.

The decision of a majority of these referees shall be final.

(Signed) Francis R. Upton.

*United States Electric Lighting Company,*
*per* Edward Weston, *Electrician.*

The test began with the following lamps entered:

| | | | |
|---|---|---|---|
| 20 Weston, | 110½ volts. | | Tamadine carbon. |
| 20 Edison, | 94–100 | " | |
| 10 Woodhouse & Rawson, | 55 | " | |
| 10 Stanley-Thompson, | 96 | " | |
| 10 " " | 44 | " | |

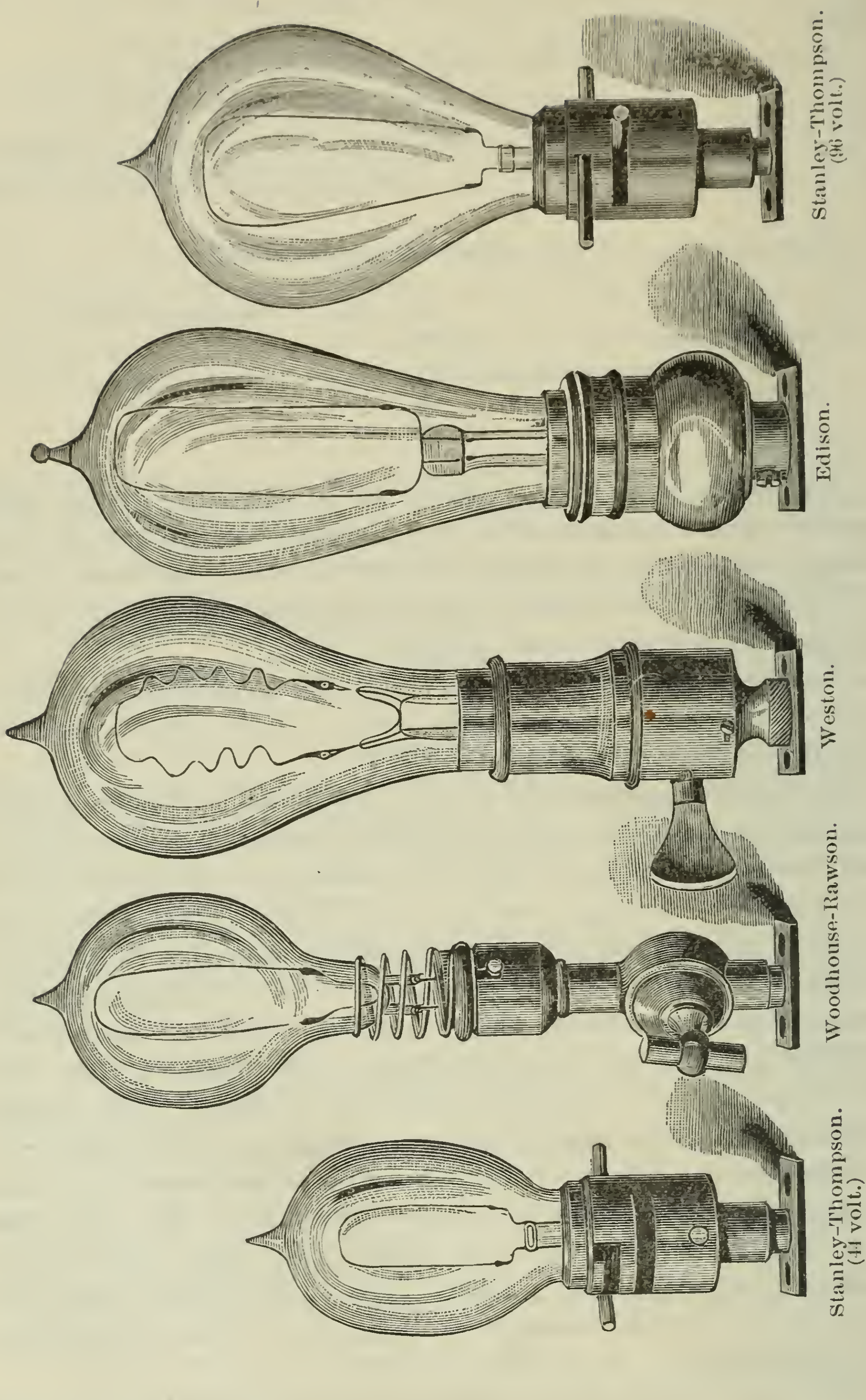
The latter lamps were requested to be entered at sixteen candle power. The committee, after a preliminary trial of several of the lamps, fixed on the potentials of 96 and 44 volts, respectively, for the two grades, as approximately representing that candle power, and the lamps were entered at these potentials.

No official information was furnished the committee as to the process of manufacture of any of the lamps. Their general appearance and the relative size is shown in Fig. 1.

The Weston lamp entered by the United States Electric Lighting Co. has what has been called a "tamadine" carbon. The committee was not furnished with any official information as to the manufacture of the lamp, but the main features were shown by Mr. Weston in his private exhibit at the exhibition, afterwards presented by him to the Franklin Institute. Gun-cotton in the form of flat sheets was treated chemically to separate the nitryl from the cellulose. The resulting cellulose product is a tough, firm, translucent substance from which the strips are cut in a sinuous form and carbonized. The carbon is rectangular in cross section, but is placed in the lamp so that at the shanks, the longer side of the rectangle is in the line of the shanks, instead of at right angles as in most other lamps. The connections are made at the terminals with minute steel screw bolts and nuts setting up with platinum washers. The bending of the carbon turns the long side of the rectangle so that it lies in different directions at different points.

The lamp is mounted on a wooden base surrounded by a brass ring.

FIG. 1.


Stanley-Thompson.
(96 volt.)
Edison.
Weston.
Woodhouse-Rawson.
Stanley-Thompson.
(44 volt.)

The wires are led down through holes in the wood to the bottom of the base, where one is soldered to a ring and the other is held in place by a small screw, which is concentric with the ring and projecting below its plane. The socket contains two spring clamps against which the terminal ring and screw of the lamp press, the lamp being held in place by a lug on the brass ring fitting into a groove in the socket. The lamps and sockets in the test were readily interchangeable and the connections were good throughout.

The Edison lamps, Fig. 1, were similar in appearance to those generally used. The carbon was made from bamboo fibre. The lamps were mounted in the ordinary screw socket, which gave good contact with great facility of handling.

The Woodhouse and Rawson lamps, Fig. 1, displayed good workmanship and were quite simple in construction. The carbon which is rectangular in cross section is cemented by a very neat joint to two platinum wires, which are kept apart by a glass bridge, and then passing through the base of the lamp have small loops formed in their ends, the loop being made rigid by imbedding the ends in the glass. Two spring hooks in the socket, hook into these loops making contact. The lamps in the test were used with Swan sockets. The loops at the base of the lamp seem liable to injury. Two lamps were disabled by the breaking of these loops before the beginning of the test for duration. No information as to the nature of the carbon was in possession of the committee. Each lamp had the firm name marked on the glass.

The Stanley-Thompson lamps, Fig. 1, had carbons apparently made from thread. No information was given other than that the lamps were made under the Stanley-Thompson patents.

The small, or 44 volt lamp, was well made, so far as the glass work was concerned, the carbon being cemented to platinum wires which were kept apart by a glass bridge and then passed through the base of the lamp. The glass bulb of the lamp was set in a hollow in a wooden base and most insufficiently secured by a cement apparently of plaster of Paris. The wires went through the wood to two small screws. Much difficulty was caused by the cement giving way, so that the wires formed the only attachment of the lamp to its base. The lamp was secured in its socket by two brass bars projecting from the sides of the wooden base, fitting into slots in a brass cylinder socket. Connections were made by two springs at the bottom of the socket pressing against the screws in the base of the lamp. The sockets were not satisfactory,

not being interchangeable readily, and difficulty was constantly met with in shifting the lamps. Several cases occurred of partial carbonization of the wooden base between the wires, causing bad leaks, and in one case it had gone so far as to attract attention by the wood's smoking. The wooden bases were blackened and the leak may have begun over this blackened surface. The difficulties met with in the 44 volt lamp were also encountered in the 96 volt. In addition there seemed to be a point of weakness in the base of the glass bulb, several of the globes breaking at that point after the cement gave way. These accidents occurred in fitting the lamps to their sockets for the test of duration.

All of the above lamps except the Edison bore evidences of the carbons having been "treated" by a deposit from a hydrocarbon gas. The deposit on the Weston carbons was but slight.

After the test for duration had continued about five hundred hours, the Franklin Institute entered three new lots of lamps as already stated. These were

| | |
|---|---|
| 10 Weston lamps (paper carbon)................................ | 70 volts. |
| 10 Woodhouse-Rawson lamps........................................ | 50 " |
| 10 White lamps.............................................................. | 50 " |

The Weston lamps were the same in general appearance as the 110½ volt lamps. The carbon, it is understood, is made from paper and subsequently treated to very heavy deposits from a hydrocarbon gas.

The Woodhouse-Rawson lamps were received indirectly from the manufacturers, and were similar in appearance to those already tested, but were more uniform.

The White lamps were somewhat similar to the Woodhouse-Rawson, in external appearance, but the bulb was somewhat longer and narrower. The carbons were cemented to platinum wires, which were separated by a glass bridge, and had loops in their ends for hook connections in a spring socket. No details of the manufacture of these lamps were furnished.

The currents were furnished by an Edison "T" dynamo, worked by a Porter-Allen engine kindly loaned for the test by the Southwark Foundry. Steam was obtained from a locomotive boiler, the property of the Franklin Institute. The potential was controlled by a Weston automatic regulator, which kept it within about a volt on either side of the normal. Three Edison bridge indicators were in use in differ-

ent parts of the circuit. They agreed in their indications and proved to be very sensitive. A registering telemanometer recorded all variations of steam pressure with great accuracy.

Although the code called for preliminary measurements for the obtaining of the reduction factor only, it was thought best to make electrical measurements as well, that the efficiencies of the lamps might be obtained in watts per spherical candle and comparisons instituted between the different lamps under test.

## PHOTOMETRIC MEASUREMENTS.

The measurements of the spherical illuminating power of the lamps were made with the object of obtaining the average candle-power of the lamps, and to avoid the doubt as to the total amount of light which might arise from the various forms of carbon (many of them distorted in manufacture), used by different makers.

Sixty-five measurements or more were made on each lamp. The method pursued may be the more easily understood by a comparison with the parallels and meridians of the earth; referring to points by their latitude and longitude.

The lamp was placed in a vertical position with the plane of the shanks of the carbon at right angles to the photometer bar. The side nearest the bar was marked for future reference. The top and bottom of the lamp were assumed as the north and south poles respectively, and the vertical circle at right angles to the plane of the shanks of the carbon as the prime meridian. The lamp, after adjustment as above, was first rotated horizontally, and thirteen measurements were made in the equator at equal angles of thirty degrees, the last checking on the first. The mean of these measurements gave the "mean horizontal intensity."

Starting again from the first position, the lamp was rotated in the plane of the prime meridian and thirteen measurements were made at equal intervals of thirty degrees, the last checking the first, and making four measurements of the point 0° latitude, 0° longitude. The mean of these four was called the "standard reading." If any noticeable discrepancy was noticed the measurements at this point were repeated. As this point was that on which the calculations for the duration test were based, its careful determination was essential.

The lamp was then moved 45° horizontally, so that 0° latitude, 45° longitude E. was towards the photometer. It was then rotated in the vertical plane passing through that point and thirteen measurements

made as before, at intervals of thirty degrees, the last checking the first.

The lamp was next moved 45° horizontally, so that 0° latitude, and 90° longitude E. was towards the photometer, and thirteen measurements made in that meridian as before.

Lastly, the lamp was rotated till 0° latitude, 135° longitude E. was towards the photometer and twelve, thirty degree measurements made in that meridian, checking with a thirteenth.

This makes a total of sixty-five measurements on each lamp. As the sockets in use with all the lamps prevented the exit of any light from the bottom or south pole of the lamp, the reading at that point was always taken as zero.

The measurements were combined as follows:

| | |
|---|---|
| The mean of four readings at the north pole of lamp | 1 |
| Four measurements on each of the parallels of 60° N. and 60° S. on the prime meridian and 90° meridian circle | 8 |
| Eight measurements on each of the parallels of 30° N. and 30° S. at the intersection of the meridian circles of 0°, 45°, 90° and 135° | 16 |
| Twelve measurements, 30° apart, on the equator | 12 |
| One zero reading for south pole (base of lamp) | 1 |
| Making a total of | 38 |

By laying down the points on a sphere it will be found that they are very nearly equidistant, being somewhat nearer at the equator than at the poles.

The average of the illuminating power at these thirty-eight points is taken at the mean spherical intensity of illuminating power.

Fig. 2 shows the location of the thirty-eight points. It is a photograph of a Mueller lamp of nearly spherical shape, around which four rubber bands are stretched to show the four meridian circles, and one rubber band to represent the equator The square black patches show the thirty-eight points.

In order to determine whether the arithmetical mean of these observations gives a close approximation to the mean spherical intensity, calculable from the observations taken, the sphere may be divided into zones, each extending 15° on either side of the equator and the parallels of 30° and 60°, and the spherical intensity be calculated from the area of these zones and the mean candle-power in each. (See Fig. 3.)

The surface of the sphere is developed at the equator by means of a

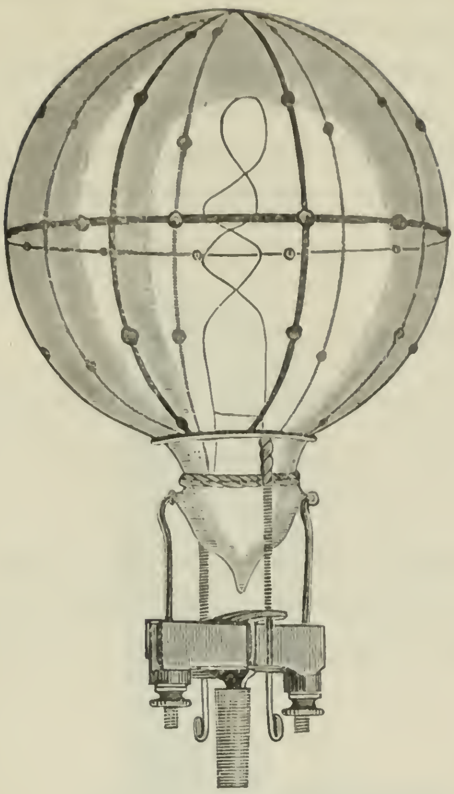


FIG. 2.--Points observed in determination of spherical intensity.

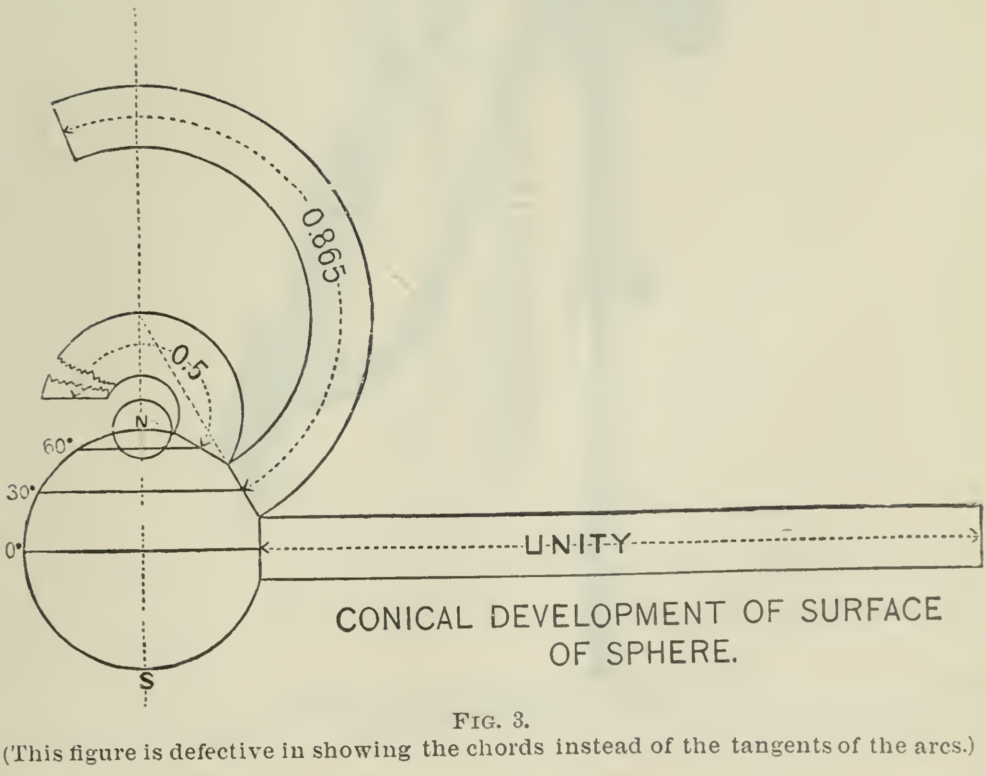



FIG. 3.
(This figure is defective in showing the chords instead of the tangents of the arcs.)

tangent cylinder, at 30° and 60° latitude by means of tangent conical frustra, and at the poles by tangent discs.

If now we multiply the mean intensity of illumination of each zone by its area and divide the sum of these products by the whole area of the sphere, we obtain with very close accuracy the mean spherical intensity of illumination. The following formula gives the method :

$$\frac{\text{Mean eq.} + \text{mean } 60° \text{ lat.} + 1{\cdot}73 \text{ mean } 30° \text{ lat.} + 0{\cdot}131 \text{ poles}}{3{\cdot}861} =$$

mean spherical candle-power.

This method when compared with that in use gives

| | |
|---|---|
| Stanley (large), No. 26......13·09 candles. | Method in use .......13·10 candles. |
| Edison, No. 2.....................14·30 " | " " ........14·38 " |

The method adopted yields results giving slight preponderance to the illumination at the equator, but the difference is small, and this method yields itself readily to the mechanical conditions of the lamp-holder.

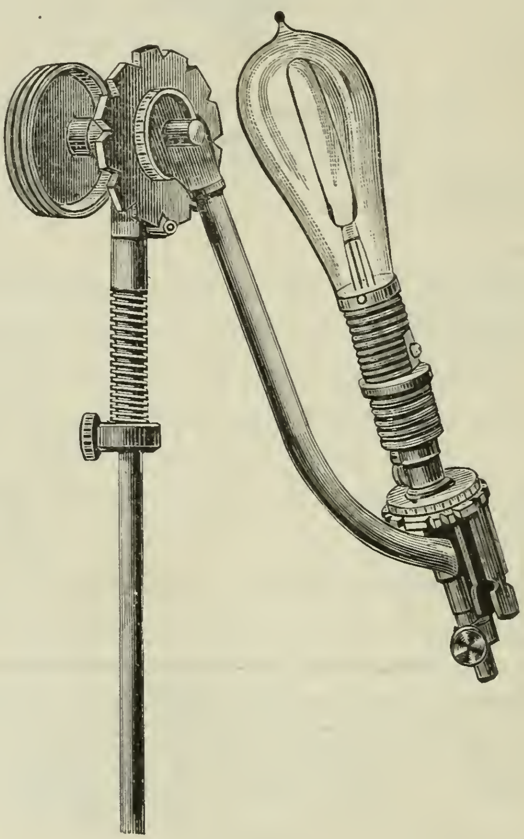


FIG. 4.—Revolving lamp holder.

From the figure it will be seen that the holder permitted the lamp to be revolved about two axes at right angles in space.

As the lamps to be measured in the preliminary efficiency test altogether required upwards of 10,000 photometric observations, it was quite important to avoid the adjustment of a graduated scale, and the horizontal and vertical axes were therefore fitted with notched plates with 12 notches each and spring catches.

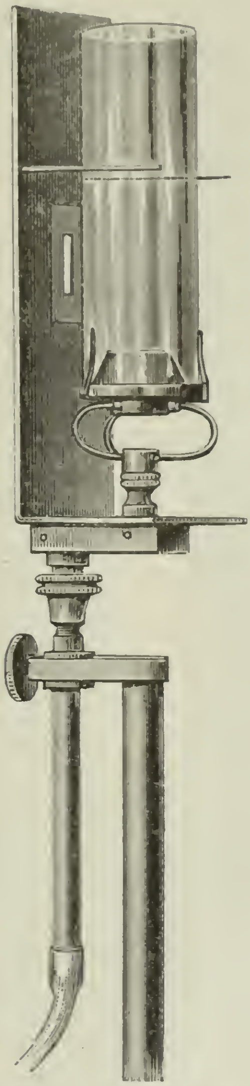


FIG. 5.—Methven Slit and Burner.

The plate for the vertical axis had two extra notches, one at 45° and one at 135°. These notched discs permitted very rapid and accurate adjustment.

The Methven standard two-candle slit was used in all the photometric measurements.

The Committee are indebted to the courtesy of Mr. Alexander P. Wright, of the United States Electric Light Company, for it and for the fittings for the photometer box.

A certificate accompanied this standard signed by Messrs. Methven & Hartley.

It was deemed wise to verify this standard independently, particularly to discover if any error due to personal equation of observer was present.

Standard English candles, a candle balance and stop watch were used in the comparison.

Ten series of five-minute observations showed an error of one per cent. as the result of 100 observations.

*Memorandum of Experiments, Comparing Weston's Methven's Standard with Standard Sugg Candle.*

| Observed Candles. | | Time. Min. | Sec. | Correction Multiplier. | Corrected Candle Power. |
|---|---|---|---|---|---|
| (1) | 1·722 | 4 | 45 | 1·052 | 1·81 |
| (2) | 1·946 | 5 | ... | None. | 1·95 |
| (3) | 1·853 | 5 | 15 | 0·952 | 1·76 |
| (4) | 2·112 | 5 | 18 | 0·943 | 1·99 |
| (5) | 2·050 | 5 | 15 | 0·952 | 1·95 |
| (6) | 1·974 | 4 | 45 | 1·053 | 2·08 |
| (7) | 2·047 | 5 | 10 | 0·968 | 1·98 |
| (8) | 1·939 | 4 | 30 | 1·111 | 2·15 |
| (9) | 2·057 | 5 | 10 | 0·968 | 1·99 |
| (10) | 2·247 | 5 | 10 | 0·968 | 2·18 |
| Mean of 100 observations.......... | | .......... | | .......... | 1·984 candles. |

Observers: G. M. Ward, Wm. D. Marks.

March 21, 1885.

Fig. 6 represents the Standard Letheby-Bunsen Photometer with 60-inch bar, used in the efficiency tests.

Two reflectors in the disc box reflected a circular Bunsen spot in paraffined paper.

The disc was always moved toward the electric lamp on the left in

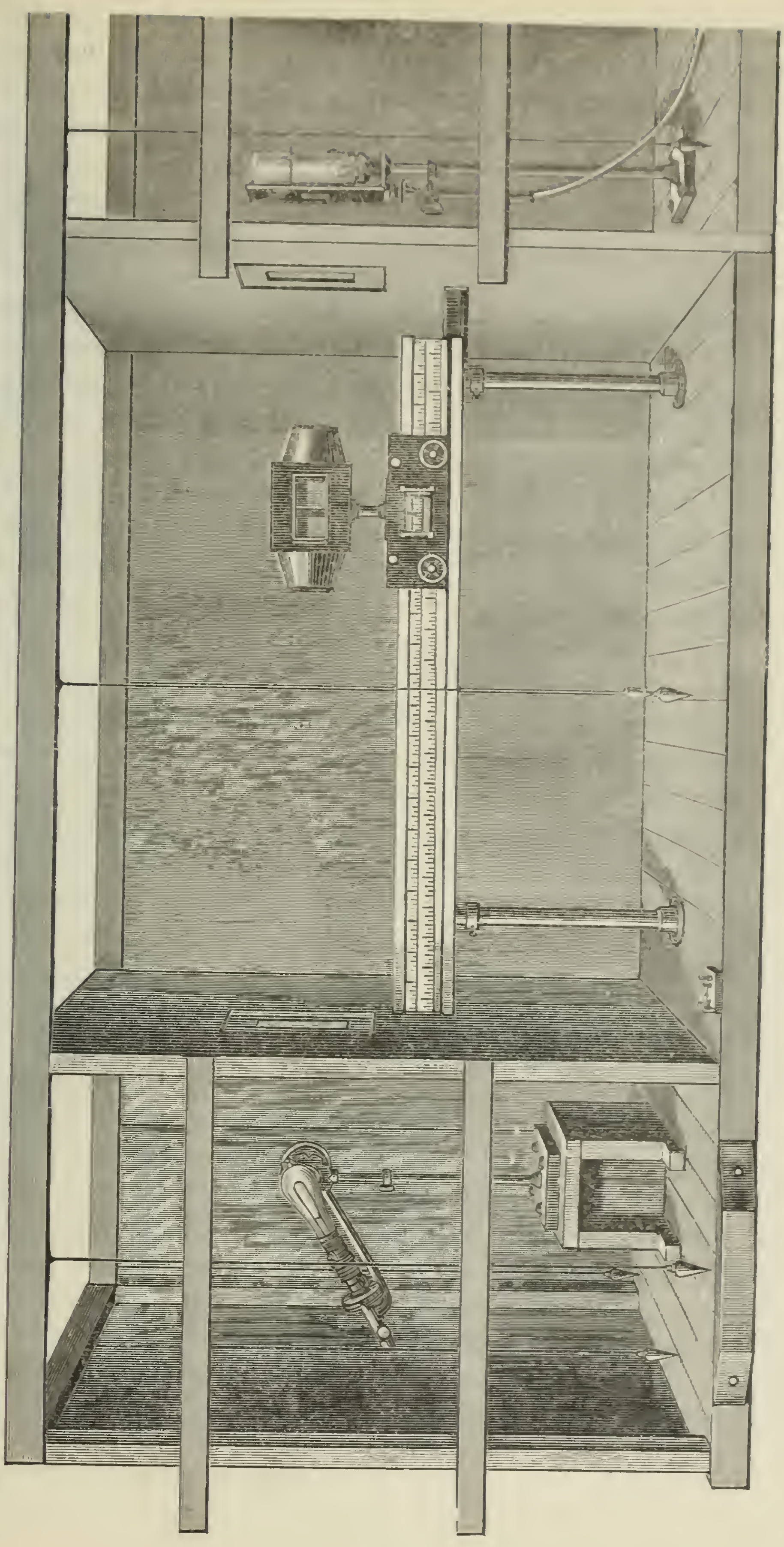


FIG. 6.—Letheby-Bunsen Photometer.

the final balancing of the illumination of the two spots; the wish of the committee being to favor alike the electric lights when in doubt.

It would appear, however, that very near exact justice has been done, since the Methven Standard, which proved to have so little error, was treated in the same manner as the lamps.

The particular lamp to be tested being placed in the lamp-holder, the potential was adjusted by means of the resistances in circuit with the lamp, and the candle power, current and potential determined. The current reached the lamp through wires dipping into mercury cups in the piece of wood at the bottom of the lamp compartment. If a change occurred in the potential, photometric work was stopped until the potential was adjusted. Observations of current were taken about every four minutes.

The "reduction factor" used during the test for duration, was obtained by dividing the mean spherical intensity of illumination by the "standard reading" or the mean of the four observations at 0° lat., 0° long.

ELECTRICAL MEASUREMENTS.

The electrical measurements were made in a small room especially prepared for the purpose. The potential of the lamps was measured by a Wiedemann mirror galvanometer in a circuit of high resistance. The instrument employed was made by Hartmann, and was chosen on account of good damping. It had a Siemens' bell magnet, suspended in a cylindrical cavity in a solid copper block. The mirror was attached to the suspending rod of the magnet. The fibre was about fifteen centimetres in length, and was without appreciable torsion within the deflections used. The deflection of the magnet was observed by a telescope and scale at a distance of 176 centimetres, afterwards increased to 180. The galvanometer resistance was about two ohms, two coils, one on each side of the magnet being used in series, but a resistance of either 50,000 or 100,000 ohms was used in circuit with the instrument, the former being employed with lamps of less than sixty volts potential, the latter with others. The galvanometer was loaned to the committee by Prof. H. D. Todd, of the U. S. Naval Academy, and the reading telescope by Messrs. Jas. W. Queen & Co., of Philadelphia, who (through Mr. Walton, the head of the Philosophical Department) extended to the committee throughout the test, every convenience that their large stock of physical apparatus afforded.

During the preliminary measurements for efficiency the potential was regulated by an observer at the telescope, who watched the deflection and recorded the potential at regular intervals, signaling any change to the photometer room, where the potential was adjusted by a change of resistance in the lamp circuit. In general this method worked well, but occasionally, through irregularity of the engine, the potential would fluctuate. Whenever the working conditions were bad the results were rejected and the measurements repeated.

The lamp currents were measured by a tangent galvanometer specially constructed for the test by Jas. W. Queen & Co. It consisted of a single coil of six turns No. 8 wire, on a brass frame of 60 cm. diameter. The base was of wood, two feet wide, resting on leveling screws. Both galvanometers stood on large wooden posts, buried two and a half feet in the earth, and out of contact with the floors or walls of the building. The needle and compass were loaned for the test by Mr. Weston. The circle was divided to 10′ and could be read by a magnifying glass to 1′ of arc. The maker's adjustments of the needle in the center of the galvanometer coil were carefully verified.

The code prescribed the method by which the electrical units should be reproduced, and was strictly adhered to.

## CURRENT.

The ampere was determined both by the silver voltameter and by calculations of the constant. During the test thirty-eight calibrations were made of the tangent galvanometer by the silver voltameter. Eight of these were purely experimental, to determine the best conditions, and several of the others were rejected on account of bad conditions. All those were accepted in which the current was steady, the deposit good, and the time accurately determined. The current was supplied at first by a gravity battery, in multiple series, but later by a secondary battery.

A solution of silver nitrate, one-half saturated, was used in a platinum crucible. The anode consisted of a spiral of silver wire, one centimetre in diameter, closely wrapped in filter paper. The crucible was held in a loop of platinum wire. The time of deposit was either twenty or thirty minutes, depending on the strength of the current. The tangent was read on both sides. The deposit was generally in vertical striæ on the inside of the crucible. Some of the later calibrations were made with a 40 per cent. solution, and this

## Table I.

*Calibrations of Tangent Galvanometer by Silver Voltameter.*

| No. | Date. | Time. | Mean deflection. | Deposit Gms. | Change in deflection. | $K = \frac{w}{zt \tan \theta}$ | |
|---|---|---|---|---|---|---|---|
| 15 | Jan. 23. | 20 | 28° 34′ | 1·1221 | 6′ | 1·5362 | Apparently reliable. |
| 16 | " 24. | 30 | 31° 35′ | 1·9042 | 32′ | 1·5391 | Apparently reliable. |
| 17 | " 24. | 30 | 31° 31′ | 1·8982 | 28′ | 1·5382 | Apparently reliable. |
| 18 | Feb. 3. | 30 | 28° 51′ | 1·7074 | 26′ | 1·5401 | Apparently reliable. |
| 19 | Mar. 3. | 30 | 31° 47′ | 1·9239 | 6′ | 1·5394 | |
| 20 | " 6. | 30 | 19° 27′ | 1·0955 | 7′ | 1·5415 | Weight uncertain, balance out of adjustment. |
| 21 | " 9. | 30 | 48° 29′ | 2·3439 | 3′ | 1·5466 | Dynamo current. Apparently reliable. |
| 22 | " 9 | ... | ......... | ......... | ......... | ......... | Not finished. Silver crystals on anode. |
| 23 | " 9. | 20 | 56° 11′ | 3·0485 | 6′ | 1·5452 | Dynamo current. Apparently reliable. |
| 24 | " 25. | 45 | 17° 09′ | 1·437 | 1° 08′ | 1·5427 | Rejected on account of unsteadiness of current. |
| 25 | " 25. | 20 | 15° 21′ | ·5703 | 1° 29′ | 1·5486 | Rejected on account of unsteadiness of current. |
| 26 | " 26. | 20 | 27° 26′ | ......... | 3° 00′ | ......... | Rejected on account of unsteadiness of current. |
| 27 | " 27. | 30 | 16° 56′ | ·9399 | 1° 10′ | 1·533 | Rejected on account of unsteadiness of current. |
| 28 | " 27. | 20 | 18° 35′ | ·6932 | 46′ | 1·537 | Rejected on account of unsteadiness of current. |
| 29 | " 27. | 20 | 22° 21′ | ·8507 | 1° 14′ | 1·542 | Rejected on account of unsteadiness of current. |
| 30 | " 28. | 20 | 21° 38′ | ·8205 | 1° 19′ | 1·542 | Rejected on account of unsteadiness of current. |
| 31 | " 31. | 20 | 19° 26′ | ·7273 | 11′ | 1·5366 | Apparently reliable. |
| 32 | April 1. | 20 | 28° 31′ | 1·1209 | 6′ | 1·5372 | Apparently reliable. |
| 33 | " 6. | 20 | 38° 32′ | 1·648 | 30′ | 1·5420 | Apparently reliable. |
| 34 | " 6. | 15 | 49° 41′ | 1·8341 | 12′ | 1·5468 | Apparently reliable. |
| 35 | " 7. | ... | ......... | ......... | ......... | ......... | Short circuit rejected. |
| 36 | May 1. | 20 | 36° 18′ | 1·5215 | 5′ | 1·5434 | Apparently reliable. |
| 37 | " 20. | 20 | 36° 55′ | 1·5585 | 10′ | 1·5437 | Uncertainty in time, due to rate of watch. Time corrected as well as possible. Rejected. |
| 38 | " 22. | 20 | 35° 02′ | 1·4639 | 4′ | 1·5452 | Uncertainty in time, due to rate of watch. Time corrected as well as possible. Rejected. |
| 39 | " 23. | 20 | 35° 01′ | 1·4515 | 18′ | 1·5442 | Apparently reliable. |
| 40 | " 25. | 20 | 28° 09′ | 1·1105 | 21′ | 1·5464 | Apparently reliable. |
| 41 | " 27. | 20 | 37° 46′ | 1·6035 | 6′ | 1·5423 | Apparently reliable. |
| 42 | " 27. | 20 | 42° 18′ | 1·8854 | 5′ | 1·5444 | Apparently reliable. |
| 43 | " 27. | 20 | 42° 25′ | 1·8941 | 5′ | 1·5452 | Apparently reliable. |
| 44 | " 27. | 17 | 35° 13′ | 1·240 | 8′ | 1·540 | Apparently reliable. |

gave a finer grained deposit. After the circuit was opened, the solution was carefully decanted from the crucible, and the deposit repeatedly washed, the washings being tested with sodium chloride. The washing was continued long after a cloudiness was obtained, and the crucible was dried at a gentle heat over a Bunsen burner. The weighings were made on a balance made by Troemner, of Philadelphia, to tenths of milligrammes. The weights used were verified by comparison with a set of standards in possession of Mr. Troemner. Table I shows the calibrations made.

The constant of the galvanometer, $K$, is derived from the voltameter determination by the formula,

$$K = \frac{W}{zt \tan. \theta}$$

$W$ being the weight of the silver deposit, $z$ Lord Rayleigh's value of the electro-chemical equivalents of silver, taken as ·06708 grammes per minute, $t$ the time in minutes, and $\theta$ the mean deflection of the galvanometer.

The error of the galvanometer in reference to the law of tangents was also calculated by the formula given in Kohlrausch's Physical Measurements, and also by Maxwell's formula. Kohlrausch's formula is

$$C = \frac{rH}{2\pi n}\left(1 + \tfrac{1}{2}.\frac{a^2}{r^2} - \tfrac{1}{3}.\frac{b^2}{r^2} - \tfrac{3}{4}.\frac{l^2}{r^2}\right)\left(1 + \tfrac{15}{4}.\frac{l^2}{r^2}\sin.^2\theta\right)\tan.\theta$$

in which $a$ = half breadth of the coil = ·45 cm.
$b$ = " depth " = ·3 "
$l$ = " length of the magnet = 1·58 "
$r$ = mean radius of the coil = 30·3 "
$n$ = number of turns in coil = 6.

The needle was 3·75 cm. in length, but its effective length between poles was assumed as $\frac{85}{100}$ of this. By substituting the above values, the errors can be calculated for different deflections $\theta$.

By substituting the same values in Maxwell's formula, the error of the coil is found to depend mainly on the coefficient $G_1$, and to be about $\frac{1}{13000}$. The error for the length of needle is shown in the following table:

| Deflection. | Error by Kohlrausch's formula. | Error by Maxwell's formula. |
|---|---|---|
| 10° | — ·0018 | |
| 15° | — ·0014 | — ·0014 |
| 20° | — ·0009 | |
| 25° | — ·0002 | — ·0002 |
| 30° | + ·0006 | |
| 35° | + ·0015 | + ·0013 |
| 40° | + ·0024 | |
| 45° | + ·0031 | + ·0031 |
| 50° | + ·0044 | |
| 55° | + ·0053 | + ·0054 |

By Kohlrausch's formula the error is zero at 26° 17′.

The voltameter determinations at different points can be compared by reducing them to 26° 17′ by means of factors derived from the formula. The following results are obtained from a curve of error constructed from Kohlrausch's values given above:

| Number. | Deflection. | K. | Correction. | K at 26° 17′. |
|---|---|---|---|---|
| 15 | 28° 34′ | 1·536 | 1·00035 | 1·536 |
| 16 | 31° 35′ | 1·539 | 1·0007 | 1·538 |
| 17 | 31° 31′ | 1·538 | 1·0007 | 1·537 |
| 18 | 28° 51′ | 1·540 | 1·0004 | 1·539 |
| 19 | 31° 47′ | 1·539 | 1·0009 | 1·538 |
| 21 | 48° 29′ | 1·547 | 1·0041 | 1,541 |
| 23 | 56° 11′ | 1·545 | 1·0055 | 1·537 |
| 31 | 19° 26′ | 1·537 | ·999 | 1·539 |
| 32 | 28° 31′ | 1·537 | 1·00035 | 1·537 |
| 33 | 38° 32′ | 1·542 | 1·0022 | 1·539 |
| 34 | 49° 41′ | 1·547 | 1·0044 | 1·540 |
| 36 | 36° 18′ | 1·543 | 1·0017 | 1·540 |
| 39 | 35° 01′ | 1·544 | 1·0015 | 1·542 |
| 40 | 28° 09′ | 1·546 | 1·0003 | 1·545 |
| 41 | 37° 46′ | 1·542 | 1·0021 | 1·539 |
| 42 | 42° 18 | 1·544 | 1·0028 | 1·540 |
| 43 | 42° 25′ | 1·545 | 1·0029 | 1·541 |
| 44 | 35° 13′ | 1·540 | 1·0015 | 1·538 |

With two exceptions, calibrations 15 and 40, the values of $K$ fall between 1·537 and 1·542, a range of less than one-third of a per cent. The mean value is 1·5381.

The code provided that the constant of the tangent should also be determined from absolute measurements. The value of $H$ was determined by a Kew magnetometer kindly loaned by Prof. C. F. Brackett, of Princeton. Owing to the presence of iron in the room, the value of $H$ was found to vary materially with changes of position or height. Two complete observations, each consisting of one set of deflections and two of vibration were made with the magnetometer needle in the exact place occupied by the needle of the galvanometer. The value of $H$ from the first set was ·19157 and from the second set ·19137. The mean of the two is ·19147. The value of the constant as calculated from the formula

Constant in amperes $= \dfrac{10\, r H}{2\pi n}$, where $r = 30·3$ cm. and $n = 6$, is 1·5389.

The calculated errors were plotted in a curve, together with the actual errors as determined by voltameter determinations, and from the mean a table of values of the constant $K$ was determined, for different points in the circle, and used throughout the test. None of the reliable calibrations, with the exception of No. 40, indicated any change in $H$ or any defect in the galvanometer, and in this case the discrepancy was but slight.

## RESISTANCE.

The ohm was by the code to be the Paris or legal ohm. In reproducing it, the committee had access to the standards and apparatus of the Johns Hopkins University, used by Prof. Rowland in his recent determination. The standard resistances of the test and the Wheatstone bridge used had their values carefully determined in Baltimore.

In the reductions the legal ohm was taken as 1·0112 B. A. units.

## ELECTROMOTIVE FORCE.

The volt was determined by the fall of potential in a given resistance due to a known current. A reel of No. 22 German silver wire was made by winding the wire on fine glass rods which were let at each end into pieces of black walnut. The turns of the wire were kept apart by turns of silk cord around the posts. The axis of the reel

was surrounded by a stirrer, by which the excessive heating of the wire while in the bath was prevented. This reel was immersed in turpentine and later in refined petroleum (300° fire test, furnished by the courtesy of the Standard Oil Co.), and while in use in calibrations the liquid was kept in motion by the stirrer and the temperature regularly recorded. The ends of the wire were taken to double binding posts at the top of the reel, to which the current and potential leads were connected.

The resistance of the reel was determined, on January 5th, at the Johns Hopkins University, as 21·089 legal ohms at 15·2° C. The reel was then placed in turpentine in the exhibition building, and remained for three weeks before the efficiency measurements began.

It was observed that the turpentine was becoming slightly greenish in color, but no change in the resistance could be detected with certainty by the only bridge at that time in the possession of the committee. As chemical action of some kind was evidently taking place, the reel was removed to a bath of refined petroleum. After the efficiency measurements, the reel was again measured and its resistance was found to have increased to 21·161 at 14° C. In order to determine whether such a change could be due to the chemical action noticed, a gramme of the wire was placed in the turpentine, and in three weeks lost three milligrammes. It was therefore considered by the committee that there was no doubt but that the change of the resistance took place before the efficiency measurements, and the later determination was used in all reductions. After the Wheatstone bridge, loaned by Messrs. Bergmann & Co., of New York, had been calibrated, the resistance of the standard coil was frequently checked. These measurements, extending from —4° C to +19, gave a coefficient of ·0004 for change of resistance per degree Cent.

Calibrations of the potential galvanometer were made by measuring the currents by the tangent galvanometer and simultaneously observing the deflection of the potential galvanometer. The lamp currents passing through the tangent affected the potential galvanometer so that it was necessary to make double readings of the latter with the currents reversed in the tangent.

Each observation with each instrument included two readings on opposite sides of zero, the mean being taken as the true deflection. This method, which was necessary in observations, was adopted for calibrations as well. Calibrations were generally made by the dynamo

currents, in default of a secondary battery. The currents used varied from one to two and a quarter ampéres, giving from twenty-one to about forty-seven volts at the terminals of the standard coil. The calibrations were generally made with the same resistance in circuit of the potential galvanometer that was used in the measurements. The constant of the potential galvanometer was taken as the potential producing a double deflection of one centimetre on the scale. Calibrations were made daily, and in case of any uncertainty were made before and after work. The value of the constant was obtained from formula

$$K = \frac{CR}{D}$$

where $C$ is the current, $R$ is the resistance of the standard coil at the temperature of the observation, and $D$ is the double deflection of the mirror in centimetres of the scale.

It was found impossible to introduce a temperature correction with any degree of accuracy. The room was warmed by a stove, and on account of the low temperature of the building, it was necessary to keep a fire in it constantly. The temperature fluctuations, although not large in amount, were generally very sudden, and anything like uniformity of temperature was unobtainable. The temperature was recorded at first and the attempt made to reduce the values obtained to a standard temperature, but the reductions were found to be of no utility. The temperature of the room ranged between 11° and 23° C. Calibrations were not made at the low temperatures, but the room was heated and kept warm for some time before calibrating. The range of temperature of the coils, while measurements were being made, was probably not more than 7°, involving an extreme possible error, from inability to determine the temperature correction, of $\frac{3}{10}$ per cent.

## MEASUREMENTS OF EFFICIENCY.

The general method of making the observations for efficiency has already been stated. The committee aimed to test each lamp at its normal potential as stated by the makers, and to place it in the test for duration at the same potential, that the relation between efficiency and life might be traced. A few lamps were tested at two or more potentials. The efficiency measurements were begun at the earliest moment when it was thought that the arrangements for the test were sufficiently advanced to secure good results.

The constant of the potential galvanometer had been determined from only a few calibrations, and the error of the tangent galvanometer was not known as well as it was later in the test. Owing to the chemical action of the turpentine on the German-silver of the standard coil used in calibrations for potential, the resistance was underestimated and the potential constant determined by calibrations was too small. After the efficiency measurements were all completed, the observations were recalculated, allowing for all known errors as determined by later measurements. The result was to raise the potential in almost every case above what was thought to be its value at the time the observations were made. In the following tables the potential is that at which the efficiency measurements were made as determined by the corrected calculations.

The diagrams show the curves of illumination in five planes passing through the centre of the lamp. The first is a horizontal plane, the equator, the others marked "vertical" are vertical planes, making angles of 45° apart. The black line in each circle shows the plane of the shanks of the carbon; the parallel lines at 0° of each circle represents the position of the photometer bar. The circles are drawn with a radius of sixteen of the scale of candle power. The following points on the different circles are coincident.

0° on horizontal and 0° on vertical 0°.
90° on horizontal and 0° on vertical 90°.
180° on horizontal and 180° on vertical 0°.
270° on horizontal and 180° on vertical 90°.

The four 90° points on the vertical sections represents the light given off at the top of the lamp.

The four 270° points in the vertical sections correspond to the base of the lamp.

The horizontal distribution is found in all the lamps tested to be dependent on the cross section of the carbon. If this is circular as it is in the Stanley and White lamp, the curve of horizontal illumination is practically a circle, if rectangular, as in the Edison and Woodhouse and Rawson, the greatest illumination is given in that direction towards which the longest side of the rectangle is turned.

Lateral twist causing the major axis of a rectangular cross section to lie in different directions at different heights in the lamp, produces a marked effect as is seen by the curve of the Weston lamp. The light given off at the top of the lamp depends in the same way on the

amount of illuminating surface visible from that point. In the Edison lamp, which has a long carbon, the two branches being comparatively close together, but little illuminating surface is visible from the top of the lamp, and but little light given off. In the Weston lamp, however, the carbon is bent into a curve, more closely approximating to a circle, and the lateral twist given the carbon turns the long side ot the rectangle in the middle of the loop towards the top. These two causes result in turning a considerable illuminating surface in that direction, and consequently in giving a large proportion of light.

The committee is indebted to Mr. C. H. Small, of the University of Pennsylvania, for the averaging of results and the construction of the light curves.

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## EDISON LAMPS.

Although only twenty-three lamps were required to be measured for the duration test, a larger number were examined, and the efficiency results are appended. The first twenty of the lamps were tested for duration, and the curves in the diagram, Fig. 7, were calculated from them. But few peculiarities were observed in these lamps. One, through a peculiar distortion of the carbon gave an almost circular curve of horizontal distribution, but the curves of the others were essentially the same as in the diagram. Owing to the causes already mentioned the potential of the lamps is generally $\frac{7}{10}$ of a volt higher than the normal. The tables give all the data of the tests. The lamps were taken at random from four hundred furnished by the company.

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## STANLEY-THOMPSON LAMPS (96 Volts).

Fourteen of the 96 volt lamps were tested for efficiency, four of the original having been broken in fitting them to sockets preparatory to the test for duration, and four others tested in their places. The high potential of lamps 37, 41 and 51 was due to an error of calculation, which, corrected after the efficiency test, gave the high figures recorded. The curves in Fig. 8 are the averages of the first eleven lamps in the table, and the averages in the plate are those of the first ten. The lamps were taken from a lot of fifty.

## STANLEY-THOMPSON (44 Volts).

These lamps gave the highest average efficiency of any lot under test, but varied considerably from each other. The curves are essentially the same as those of the 96 volt lamps, except in giving less light at the top of the lamp. The lamps were taken at random from a lot of fifty.

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## WOODHOUSE and RAWSON LAMPS.

Two lots of these lamps were tested. The results obtained were generally the same. The first lot were marked 55 volts, and were taken from twenty-five lamps furnished. The slight irregularities in the curves (Fig. 10) are due to the fact that the lamp was mounted on a spring socket (Swan) in the efficiency measurements, and the motion and vibration of this socket in moving it through the various positions occupied, prevented as accurate measurements as in other cases, where the lamp was held rigidly.

The second set of Woodhouse and Rawson lamps, selected from fifty furnished, were marked 50 volts, and a paper accompanying them from the makers, invoiced them as "20 candle-power, 50 volt" lamps. They were tested by the committee, as the duration test on the former lot was unsatisfactory by reason of many of the lamps being connected two in series. On setting the new lot up at 50 volts, they were found to give only twelve spherical candles, and to have an efficiency of about five watts per candle. The Woodhouse and Rawson is known as a very economical lamp, and has of late attracted much interest on that account. A duration test of 300 hours was all that could be allotted to these lamps and would determine nothing if the lamps were tested at so low candle power. As the resistance of the lamps cold was the same as some of the first lot of 55 volts, the committee determined to test the second lot at that potential also, with a statement of the facts.

## WHITE LAMPS.

These lamps were taken from a lot of twenty-four. The carbon is apparently made of thread, has a circular cross-section, and is heavily treated. The curves of the whole lot are almost identical. The lamps were tested with spring sockets received from the Electrical Supply Co., and to the vibrations and lack of rigidity of this socket during the revolutions of the lamp holder, is attributed the slight want of symmetry observable in the curves in Fig. 11. The cold resistance in the table of the figure is unquestionably an error, but was not discovered until too late for correction. The lamps decreased in resistance during the duration test. The average cold resistance before use, of several lamps of the same lot, was found to be 102 ohms, and those under test probably averaged about the same.

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## WESTON LAMPS ($110\frac{1}{2}$ VOLTS).

In submitting a report on the tests of these lamps, the committee think it proper to give a resumé of correspondence between Mr. Weston and themselves. The $110\frac{1}{2}$ volt lamps were received from the United States Company in January. Efficiency measurements were made on the 5th, 6th and 7th of February. On the 18th of February, Mr. Weston visited the exhibition building, was shown the results of the efficiency measurements on his lamps, examined into the installation, and the working methods of the test, and thinking the candle-power of some of them low, addressed the following to the committee:

PHILADELPHIA, February 18, 1885.

Having examined the methods of testing used and the results obtained in the efficiency determinations, I would request a re-measurement of my lamps numbered 4, 6, 15 and 17.

I am satisfied that the methods used are such as will produce correct results.

EDWARD WESTON.

The lamps designated were re-tested and the accuracy of the former measurements verified. On the 7th of March the preliminary run for working methods began. Owing to irregular working of the engine, causing flickering in the lamps, it was prolonged a week, that better

working might be secured. On March 17th the committee had arranged to begin the duration test at 2 P. M. Very shortly before that time, the representative of the United States Company, who had not been in attendance on the tests for several weeks, although his presence had frequently been solicited, arrived with the following letter from Mr. Weston:

LABORATORY OF EDWARD WESTON, 107 ORANGE STREET,
NEWARK, N. J., March 16, 1885.

PROF. WM. D. MARKS.

DEAR SIR:—The very marked difference in candle-power of our lamps, as shown in the tabulated results of the tests made in Philadelphia, surprised me very much, particularly as our lamps are remarkably uniform in this respect, and must necessarily be so when properly made, owing to the peculiar method of treating the loops.

After arriving here I commenced to investigate the matter, and soon found that you had been supplied with a singularly bad lot of lamps; the defect being due to imperfect baking of the loops. This has been so imperfectly done that you will find it impossible to maintain the candle-power uniform for even a very short period of time without increasing the E. M. F. The resistance of the loops will rise rapidly, and the lamps will rapidly deteriorate and fail in such a short time, as to leave no doubt in your mind that if we made such lamps regularly we could not possibly continue to do business. In other words, the lamps are thoroughly worthless.

In view of these facts I think it is useless to spend any time on the lamps of our make which you now have, and since there is no provision in the code for such a contingency as has arisen, I respectfully submit this statement of facts to the committee, and ask for a careful consideration of the matter.

Deeply regretting that anything should have occurred on our part to still further prolong, and increase the cost of a series of tests which must necessarily be very tedious and expensive, I remain,

Yours, respectfully,

EDWARD WESTON.

The members of the committee present agreed with Mr. Weston that the code provided no remedy for a case of this kind, and agreed to postpone the beginning of the test and to refer the matter to the Edison Company, that the competing parties might enter upon new arrangements. The Edison Company through Mr. Upton agreed that Mr. Weston should have the privilege of entering another lot of lamps of the same general character and grade as those already tested, and the committee desirous of obtaining good lamps for test, agreed to measure them when received. On the 1st of April a conference took place

between Messrs. Weston and Upton, the president of the FRANKLIN INSTITUTE and a portion of the committee, at which Mr. Weston stated he thought there would be no doubt but that the new lot of lamps would be on hand within a week. The allotted time expiring without anything being heard from him, the following letter was sent:

PHILADELPHIA, April 8, 1885.

Mr. EDWARD WESTON,

*Electrician of the U. S. Electric Light Co.,*

*Newark, New Jersey.*

DEAR SIR:—Since your letter of March 16th, 1885, the committee of the FRANKLIN INSTITUTE appointed to conduct the competitive duration test of electric incandescent lamps have been awaiting the receipt of other lamps to replace those which in your letter you condemned and pronounced worthless. Our letter of the 17th ultimo conveyed to you an expression of our willingness to undertake the additional labor necessary to test a new lot of lamps. Hearing nothing further from you regarding lamps, we telegraphed for date and received no reply, on March 26th. On March 30th, a fortnight later than your letter, we wrote to say that the tests would begin April 3, unless some sufficient reason for delay was assigned. At our verbal conference of April 1st, our understanding was that your new lamps would certainly reach us by to-day. We again telegraphed you yesterday afternoon. The engagements of some of the members of the committee will prevent the completion of the duration test if further postponement occurs. In justice to the FRANKLIN INSTITUTE this test must be completed.

The committee in the absence of any reply relative to our telegram of yesterday, feel compelled to fix Saturday the 11th, current, as the date beyond which further postponement is impossible. This will have given you twenty-five days in which to replace lamps pronounced worthless in your letter of March 16th. The committee have stretched the allowable time of delay to the utmost and regret the imperative necessity which forces them to fix a limit to it.

The committee interprets your letter of the 16th as a withdrawal of your lamps of the 40 grade (110½ volt.)

If new lamps of similar grade are not received by Saturday forenoon, April 11th, the duration test will proceed without your lamps and the United States Electric Light Co. will not be regarded as a competitor. The 70 volt lamp now measured will, however, be tested as a matter of scientific interest, but not in competition with other lamps.

We regret that circumstances force us to make this decision, and will be more than pleased to have you enter as a competitor. Our limited time and means will not permit further delay.

I am, very truly yours,

WM. D. MARKS.

This letter was written with the knowledge of only a portion of the

committee, who assumed that the Edison Company would not compete with lamps pronounced worthless by their maker.

On April 9th another conference was held at which the representative of the Edison Company objected to Mr. Weston withdrawing his lamps, and addressed the following letter to the committee:

Prof. Wm. D. Marks, *Chairman.*

Dear Sir:—The Edison Company desire that the test of lamps be proceeded with under the code without further delay.

Respectfully,

Francis R. Upton.

65 Fifth avenue, April 9th, 1885.

This request that the test should be continued under the code, the failure of Mr. Weston to provide new lamps, together with the impossibility of further delay if the test was to take place at all, gave the committee no option, but to proceed under the code with the lamps on hand. In order to prevent any misunderstanding on the part of Mr. Weston, he was notified by letter and telegram that the test would begin on the 11th. A few hours after the beginning of the test, the following telegram was received:

Prof. Wm. D. Marks.

Your telegram surprised me. The lamps have been withdrawn. Our position in this respect is fully caused by your letter of April 8th. I presumed that this was the final judgment of the committee pending a reply from me. There is no clause in the code by which the Edison Company can compel the committee to proceed as indicated in your telegram, neither the committee nor the Edison Company have any right to re-enter our lamps without our consent. My letter in reply to yours of the 8th will fully cover these points.

Edward Weston.

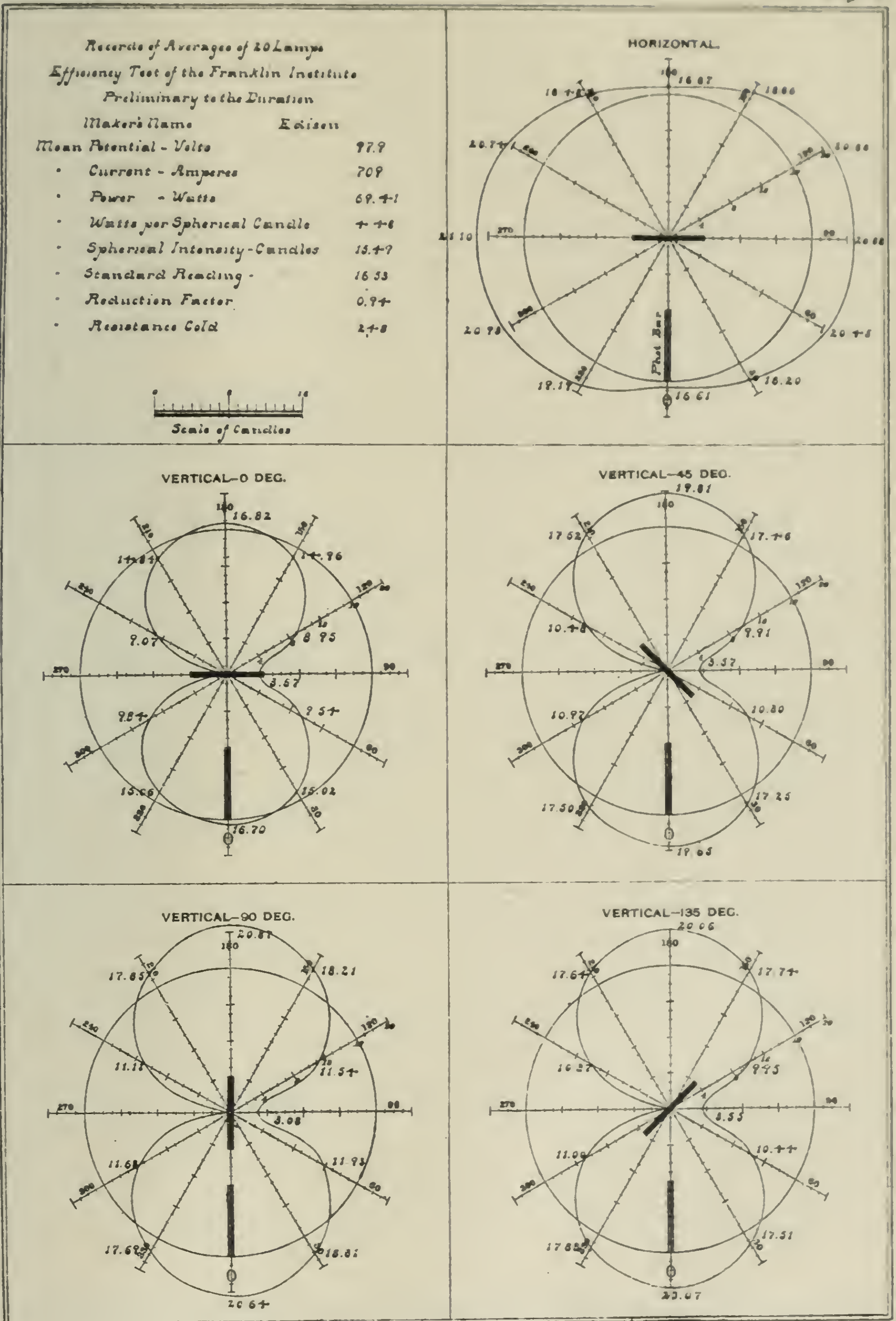
The matter was immediately considered by the full committee and answered as follows:

Philadelphia, April 11, 1885.

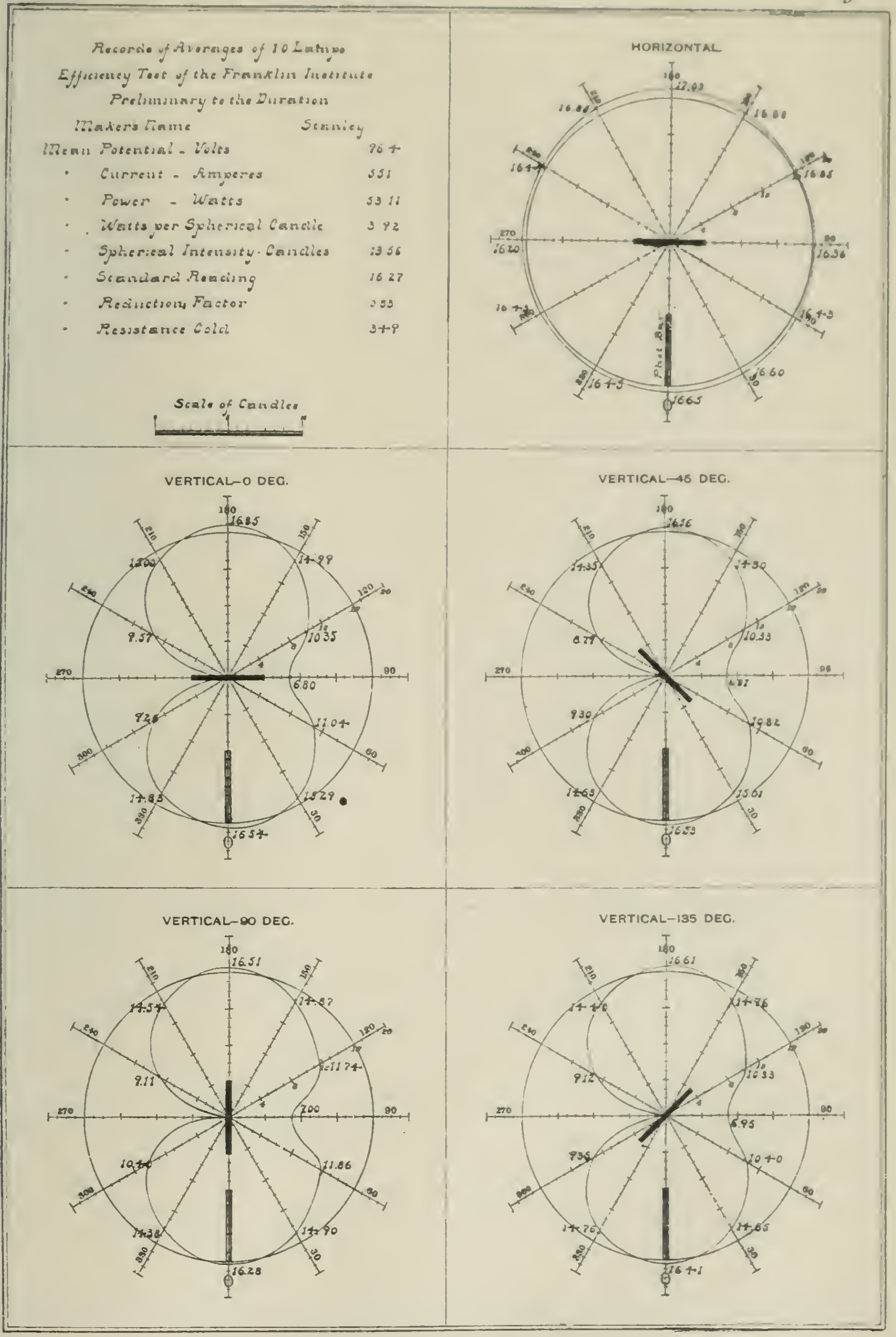
Edward Weston,

*Newark, New Jersey.*

In reply to your telegram of to-day the committee have considered the question you raise. It was understood by them that the verbal conference of Thursday evening at which you were present, made it clear that the formal demand of one of the competitors that the test should proceed, left the members of the committee then present no option in the matter and rendered the letter of the 8th nugatory. Under the provisions of the code any questions between the contestants and the committee can be settled by a unanimous vote of the committee, and the undersigned give their deci-




Test of Incandescent Electric Lamps.

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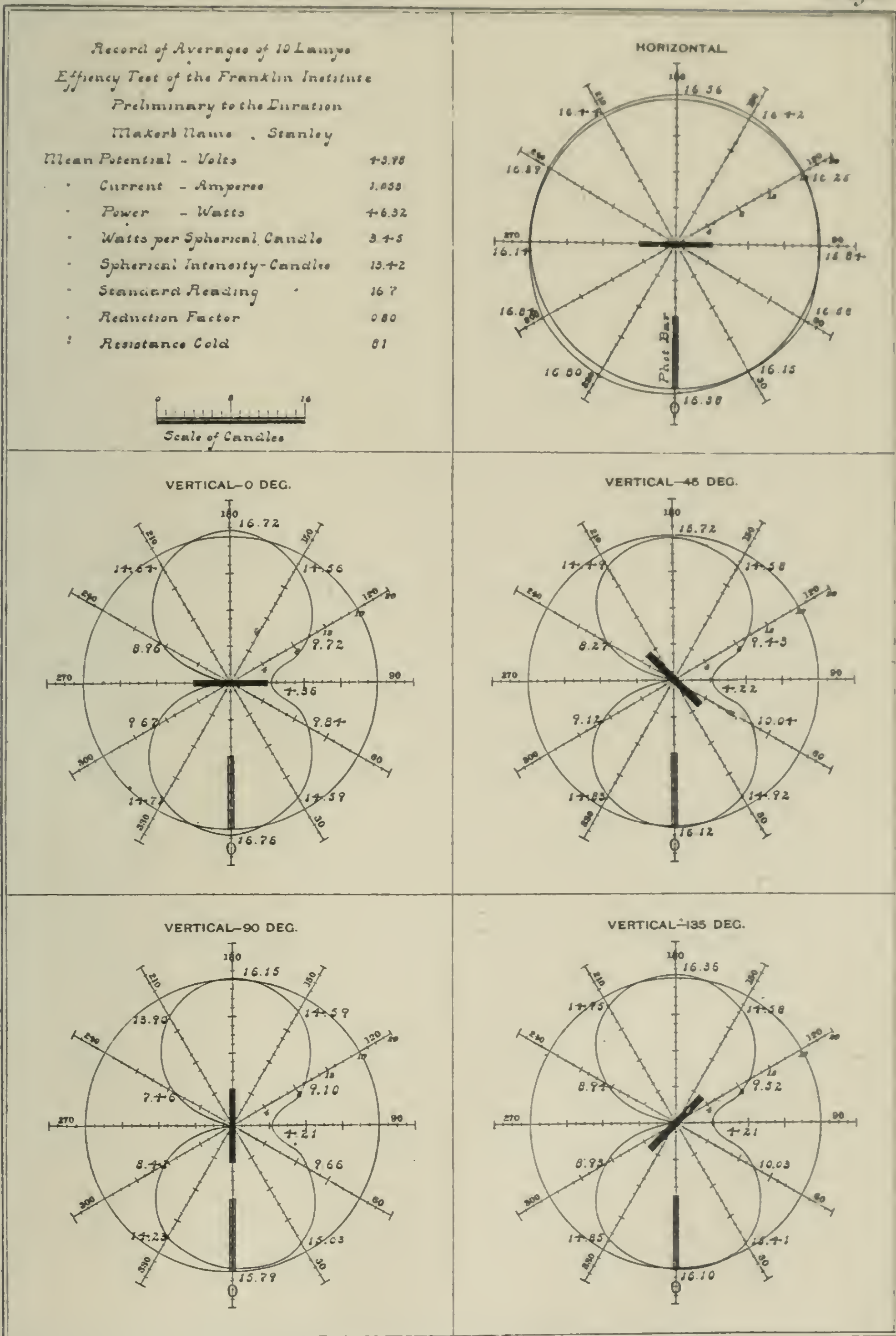


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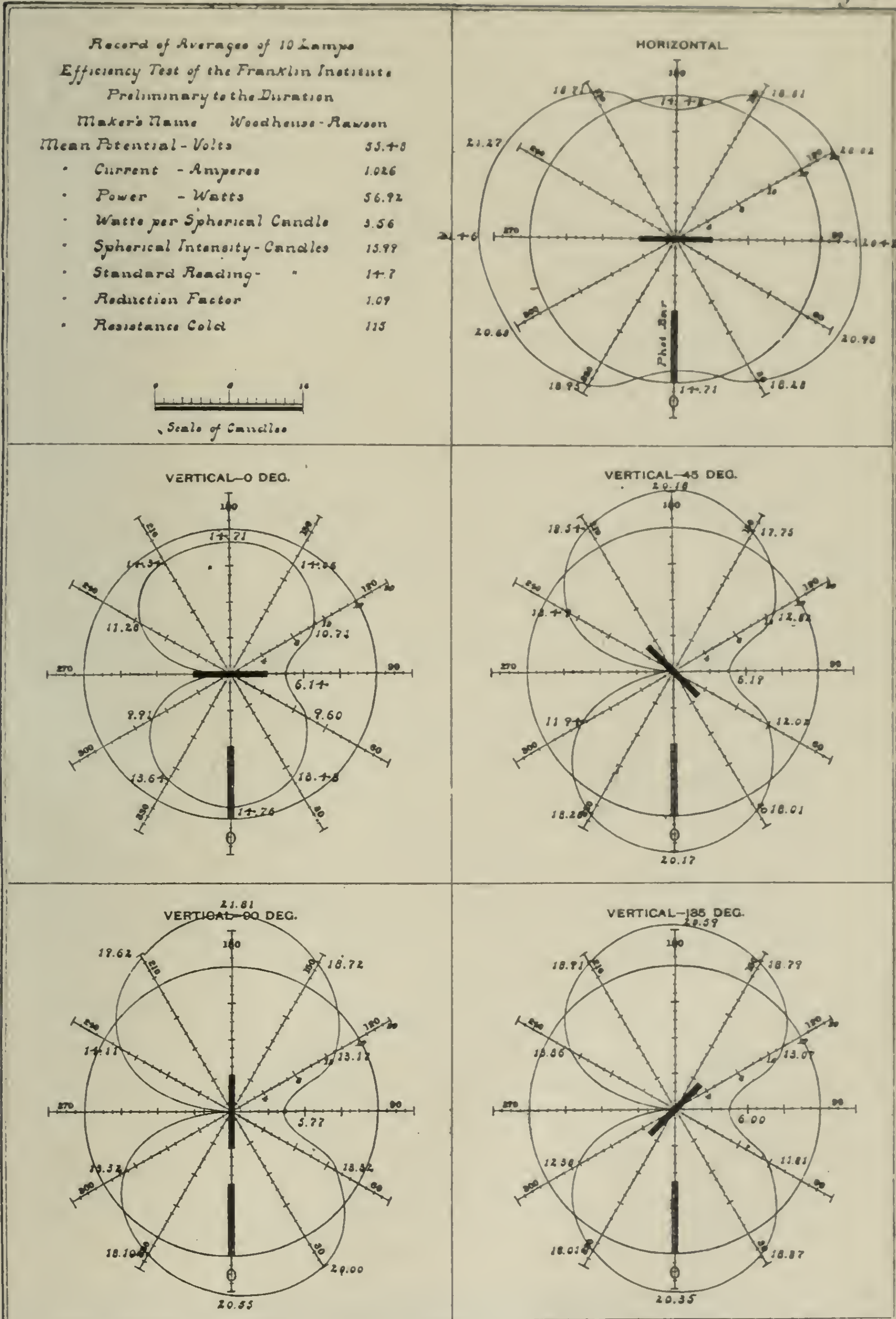


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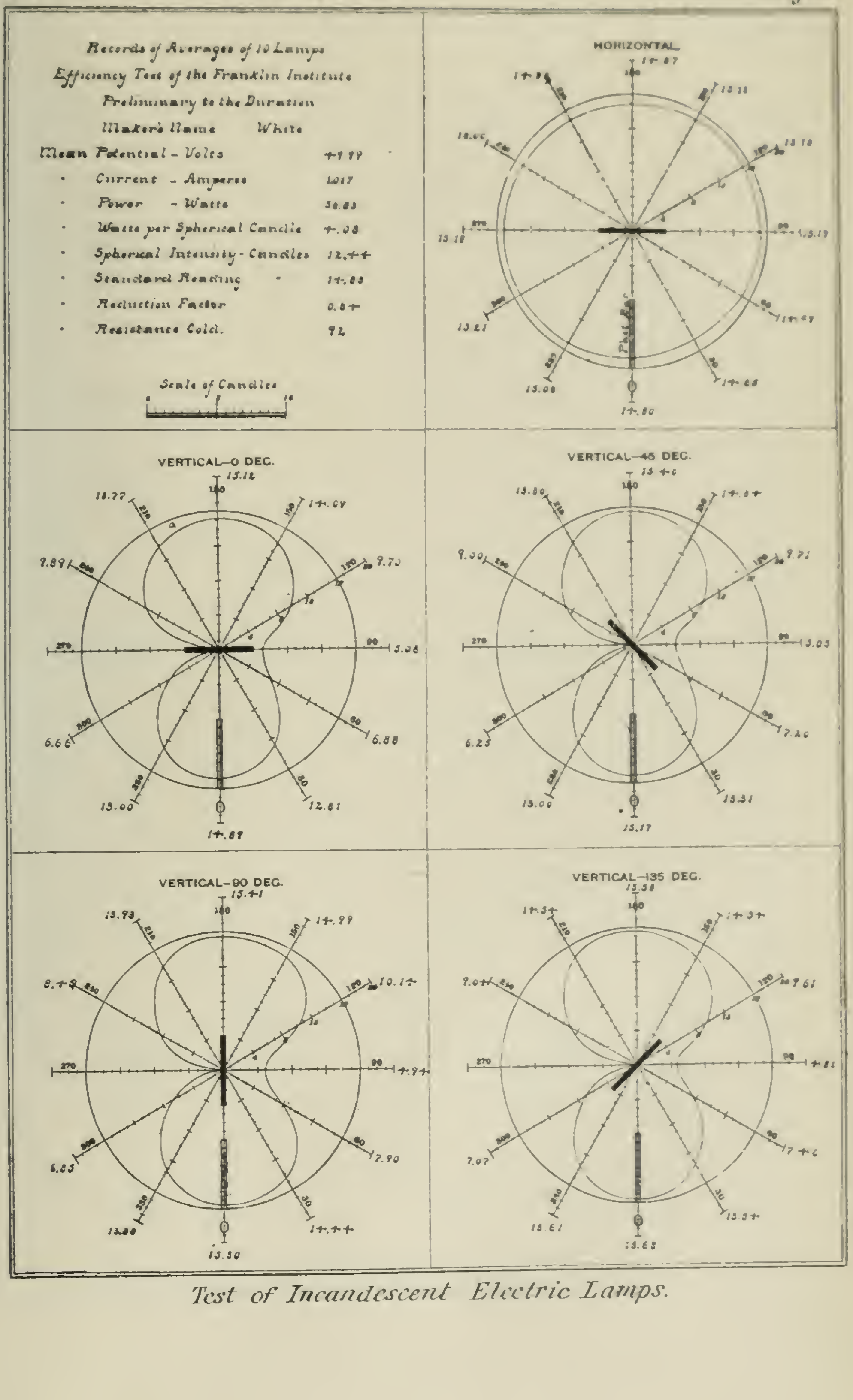
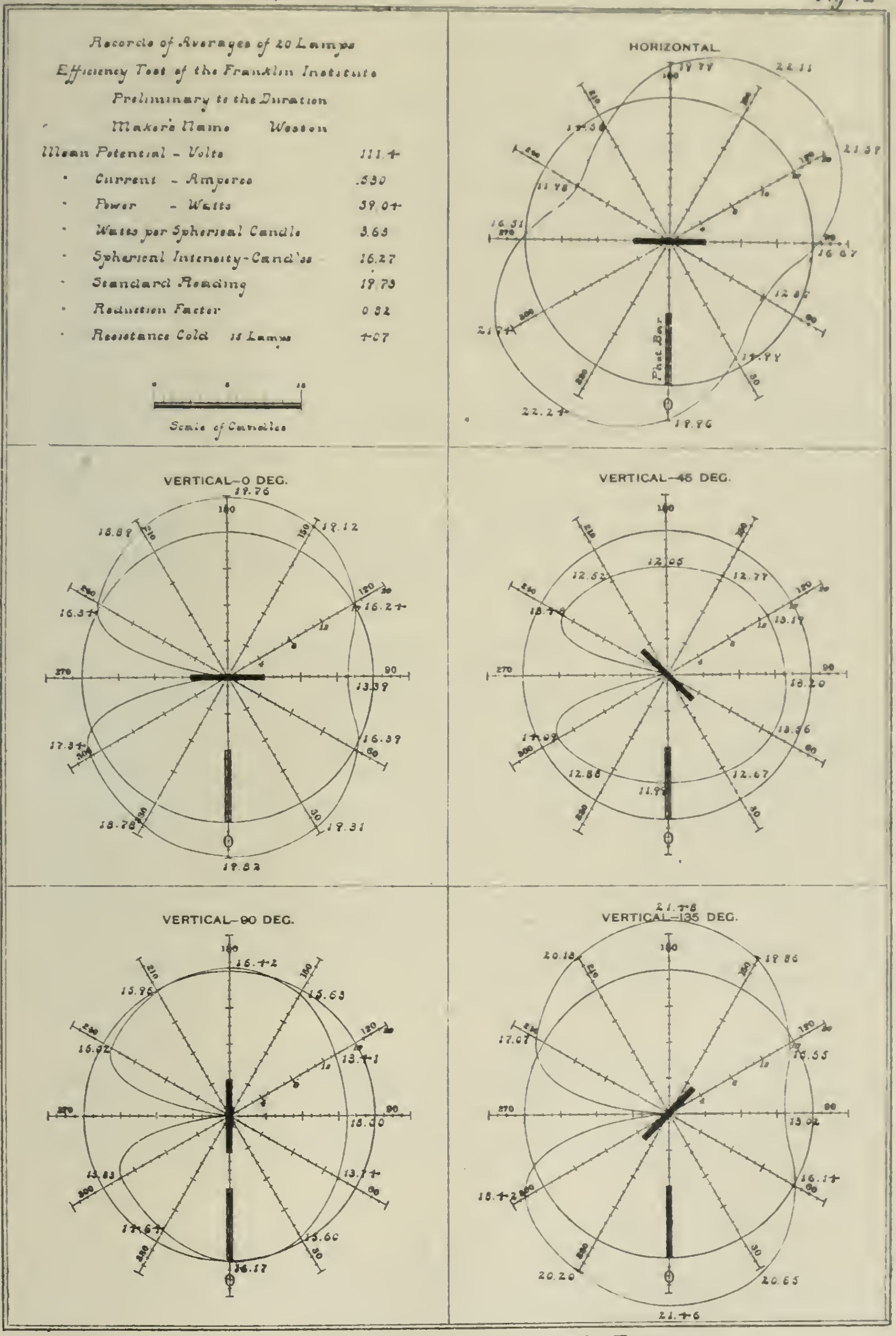



*Test of Incandescent Electric Lamps.*




Test of Incandescent Electric Lamps.

sion that under the code no withdrawal is possible, and their letter of the 8th becomes invalid when questioned by a contestant.

J. B. MURDOCK, G. M. WARD,
L. DUNCAN, WM. D. MARKS.

Subsequently another letter was received from Mr. Weston and another conference held at his request, but the committee regarded their action as final and nothing was done.

The committee present the above as a matter of justice to Mr. Weston and also as an explanation of their own course of action.

Reference has already been made to the peculiar form of the Weston carbon. The light curves were very similar in form in all the lamps. In one, the major axis of the curve of horizontal illumination lay in the direction of 30°–210° instead of in 330°–150° as in the figure. In making up the average of twenty, another lamp was substituted for this one.

The results of the preliminary efficiency measurements are given in the following tables and diagrams.

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## WESTON LAMPS (70 VOLTS.).

Mr. Weston having expressed a desire to have measurements made on a lot of 70-volt paper carbon lamps, they were entered by the president of the FRANKLIN INSTITUTE for test. The distribution of light is almost exactly the same as in the other lot. Ten lamps were selected from a lot of thirty-three received from Mr. Weston, tested for efficiency and afterwards subjected to a duration test of 523 hours.

In addition to Mr. Weston's approval of the methods adopted in the test, as stated in his letter of February 18th, the committee received the following:

PHILADELPHIA, March 6th, 1885.

Having examined the methods of testing used and the results obtained in the efficiency test now being made by the FRANKLIN INSTITUTE, I am satisfied that the methods used are such as will produce correct results.

FRANCIS R. UPTON.

PHILADELPHIA, February 13, 1885.

Having been personally present during the determination of the efficiency of the lamps entered for the duration test, and having examined the instruments used, the methods pursued and the operations of the experimenters, I am of the opinion that the tests are fairly conducted and that the methods used are such as to produce correct results.

JOHN W. HOWELL.

## Table II.—*Edison Lamps.*

| Lamp. | Volts. | | Amperes. | Watts. | Candles. | | Watts per Spher. Cand. | Resistance. | | Stand'rd Reading. | Reduc'n Factor. | Candles per Elec. H.P. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mk'd. | Obsrv'd. | | | Mean Spherical. | Mean Horizont'l | | Cold. | Hot. | | | Spherical. | Horizont'l |
| 1 | 99 | 98·9 | ·690 | 68·24 | 15·31 | 18·81 | 4·45 | 260· | 143·3 | 15·90 | ·96 | ............ | ............ |
| 2 | 98 | 98·9 | ·703 | 69·44 | 14·38 | 17·62 | 4·83 | 252· | 140·7 | 13·95 | 1·03 | ............ | ............ |
| 3 | 95 | 95·8 | ·711 | 68·12 | 14·87 | 18·03 | 4·58 | 241· | 134·7 | 16·32 | ·91 | ............ | ............ |
| 4 | 95 | 95·8 | ·718 | 68·79 | 15·72 | 19·44 | 4·37 | 241· | 133·4 | 16·90 | ·93 | ............ | ............ |
| 5 | 97 | 97·8 | ·718 | 70·21 | 16·41 | 20·28 | 4·27 | 244· | 136·2 | 17·32 | ·95 | ............ | ............ |
| 6 | 99 | 99·9 | ·692 | 69·13 | 14·67 | 17·98 | 4·71 | 264· | 144·4 | 16·07 | ·91 | ............ | ............ |
| 7 | 95 | 95·8 | ·736 | 70·31 | 14·57 | 18·43 | 4·82 | 235· | 130·2 | 16·50 | ·88 | ............ | ............ |
| 8 | 97 | 97·9 | ·729 | 71·37 | 16·81 | 20·32 | 4·24 | 239· | 134·3 | 19·97 | ·84 | ............ | ............ |
| 9 | 95 | 95·8 | ·718 | 68·79 | 15·11 | 18·51 | 4·55 | 240· | 133·4 | 15·10 | 1·00 | ............ | ............ |
| 10 | 97 | 97·8 | ·714 | 69·83 | 14·58 | 18·54 | 4·79 | 246· | 137·0 | 14·92 | ·98 | ............ | ............ |
| 11 | 98 | 98·7 | ·711 | 70·18 | 16·66 | 20·98 | 4·21 | 250· | 138·8 | 18·25 | ·91 | ............ | ............ |
| 12 | 98 | 98·8 | ·686 | 67·77 | 13·76 | 17·48 | 4·92 | 254· | 144·0 | 14·72 | ·93 | ............ | ............ |
| 13 | 96 | 96·7 | ·723 | 69·91 | 15·44 | 19·00 | 4·52 | 235· | 133·7 | 16·67 | ·93 | ............ | ............ |
| 14 | 96 | 96·7 | ·707 | 68·37 | 15·62 | 19·70 | 4·37 | 245· | 136·8 | 16·63 | ·94 | ............ | ............ |
| 15 | 99 | 99·7 | ·692 | 68·99 | 15·65 | 19·74 | 4·40 | 255· | 144·1 | 14·30 | 1·09 | ............ | ............ |
| 16 | 95 | 95·7 | ·714 | 68·33 | 16·09 | 20·26 | 4·24 | 239· | 134·0 | 20·30 | ·79 | ............ | ............ |
| 17 | 98 | 98·8 | ·701 | 69·26 | 16·61 | 21·10 | 4·17 | 259· | 140·9 | 17·98 | ·92 | ............ | ............ |
| 18 | 97 | 97·7 | ·708 | 69·17 | 15·60 | 19·25 | 4·43 | 242· | 138·0 | 16·34 | ·96 | ............ | ............ |
| 19 | 99 | 99·7 | ·714 | 71·19 | 16·02 | 19·50 | 4·44 | 250· | 139·6 | 16·15 | ·99 | ............ | ............ |
| 20 | 100 | 100·7 | ·696 | 70·09 | 15·82 | 19·56 | 4·43 | 256· | 144·7 | 16·23 | ·97 | ............ | ............ |
| 21 | 97 | 97·7 | ·698 | 68·19 | 16·71 | 20·95 | 4·08 | 250· | 140·0 | 17·27 | ·97 | ............ | ............ |
| 22 | 97 | 97·8 | ·719 | 70·32 | 16·13 | 20·36 | 4·36 | 241· | 136·0 | 16·27 | ·99 | ............ | ............ |
| 23 | 97 | 97·0 | ·719 | 69·74 | 15·68 | 19·67 | 4·44 | 247· | 135·2 | 19·00 | ·83 | ............ | ............ |
| 24 | 95 | 95·0 | ·705 | 66·98 | 15·04 | 18·57 | 4·45 | 238· | 134·8 | 15·95 | ·91 | ............ | ............ |
| 25 | 98 | 98·7 | ·714 | 70·47 | 15·42 | 19·43 | 4·57 | 253· | 138·2 | 14·92 | 1·03 | ............ | ............ |
| 26 | 96 | 95·9 | ·700 | 67·13 | 15·11 | 19·24 | 4·44 | 248· | 137·0 | 15·95 | ·95 | ............ | ............ |
| 27 | 95 | 95·8 | ·668 | 64·00 | 15·33 | 19·20 | 4·17 | 259· | 143·4 | 17·30 | ·89 | ............ | ............ |
| 28 | 99 | 99·8 | ·692 | 69·06 | 14·90 | 18·38 | 4·63 | 254· | 144·2 | 16·70 | ·90 | ............ | ............ |
| 29 | 95 | 95·7 | ·697 | 66·70 | 15·24 | 18·38 | 4·37 | 243· | 137·3 | 15·10 | 1·01 | ............ | ............ |
| 30 | 95 | 95·7 | ·696 | 66·61 | 14·97 | 18·42 | 4·45 | 244· | 137·5 | 16·65 | ·90 | ............ | ............ |
| 31 | 98 | 98·0 | ·713 | 69·87 | 15·40 | 19·24 | 4·53 | 247· | 137·4 | 15·40 | 1·00 | ............ | ............ |
| ............ | 96·9 | 97·57 | ·7065 | 68·92 | 15·47 | 19·24 | 4·459 | 247·5 | ......... | ......... | ......... | 169·2 | 210·4 |

TABLE III.—*Stanley Lamps, 96 Volts.*

| Lamp. | Volts. | Amperes. | Watts. | Candles. | | Watts per Spher. Cand. | Resistance. | | Stand'rd Reading. | Reduc'n Factor. | Candles per Elec. H.P. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Mean Spherical. | Mean Horizont'l | | Cold. | Hot. | | | Spherical. | Horizont'l |
| 26 | 96·4 | ·578 | 55·72 | 13·10 | 15·73 | 4·25 | 330· | 166·8 | 15·85 | ·82 | ............ | ............ |
| 27 | 96·4 | ·538 | 51·86 | 10·25 | 12·33 | 5·06 | 359· | 179·2 | 12·52 | ·82 | ............ | ............ |
| 28 | 96·5 | ·584 | 56·35 | 17·11 | 19·78 | 3·29 | 328· | 165·2 | 19·80 | ·86 | ............ | ............ |
| 29 | 96·4 | ·537 | 51·76 | 16·49 | 19·48 | 3·14 | 368· | 179·5 | 19·82 | ·83 | ............ | ............ |
| 30 | 96·3 | ·514 | 53·35 | 12·94 | 15·65 | 4·12 | 339· | 173·8 | 15·35 | ·84 | ............ | ............ |
| 31 | 96·4 | ·529 | 50·99 | 9·91 | 12·49 | 5·14 | 357· | 182·2 | 12·58 | ·79 | ............ | ............ |
| 32 | 96·5 | ·559 | 53·94 | 13·54 | 16·37 | 3·98 | 341· | 172·6 | 15·90 | ·85 | ............ | ............ |
| 33 | 96·4 | ·528 | 50·90 | 14·32 | 17·17 | 3·55 | 365· | 182·6 | 17·45 | ·82 | ............ | ............ |
| 34 | 96·4 | ·558 | 53·79 | 14·17 | 16·95 | 3·79 | 349· | 172·8 | 17·05 | ·89 | ............ | ............ |
| 35 | 96·4 | ·552 | 53·21 | 13·72 | 16·59 | 3·87 | 350· | 174·6 | 16·38 | ·82 | ............ | ............ |
| 36 | 96·2 | ·576 | 55·41 | 16·49 | 19·55 | 3·36 | 336· | 167·0 | 19·92 | ·83 | ............ | ............ |
| 37 | 97·2 | ·531 | 51·90 | 14·28 | 17·29 | 3·63 | 350· | 182·0 | 17·55 | ·81 | ............ | ............ |
| 41 | 97·2 | ·567 | 55·11 | 12·93 | 15·51 | 4·26 | 340· | 171·4 | 15·97 | ·81 | ............ | ............ |
| 51 | 97·2 | ·578 | 56·18 | 11·01 | 13·28 | 5·10 | 320· | 168·2 | 13·52 | ·81 | ............ | ............ |
| | 96·56 | ·554 | 53·61 | 13·59 | 16·30 | 4·04 | 345·1 | ....... | ....... | ...... | 189·1 | 226·3 |

TABLE IV.—*Stanley Lamp, 44 Volts.*

| Lamp. | Volts. | Ampéres. | Watts. | Candles. | | Watts per Spher. Cand. | Resistance. | | Standard Reduc'n | | Candles per Elec.H.P. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Mean. Spherical. | Mean Horizont'l | | Cold. | Hot. | Reading. | Factor. | Spherical. | Horizont'l |
| 1 | 44·40 | 1·096 | 48·66 | 12·39 | 15·36 | 3·92 | 80·7 | 40·51 | 15·2 | ·82 | ............ | ............ |
| 2 | 44·45 | 1·039 | 46·18 | 11·10 | 13·38 | 4·16 | 84·0 | 42·78 | 14·0 | ·79 | ............ | ............ |
| 3 | 43·90 | 1·068 | 46·88 | 15·88 | 19·46 | 2·95 | 79·5 | 41·10 | 19·7 | ·81 | ............ | ............ |
| 4 | 43·90 | 1·080 | 47·41 | 14·07 | 17·40 | 3·36 | 79·2 | 40·65 | 18·3 | ·77 | ............ | ............ |
| 6 | 43·90 | 1·001 | 43·94 | 10·31 | 12·58 | 4·26 | 85·0 | 43·86 | 13·1 | ·79 | ............ | ............ |
| 7 | 43·90 | 1·078 | 47·32 | 12·46 | 15·15 | 3·79 | 78·0 | 40·72 | 15·5 | ·80 | ............ | ............ |
| 8 | 43·90 | 1·014 | 45·83 | 10·58 | 12·92 | 4·33 | 79·8 | 42·05 | 12·1 | ·87 | ............ | ............ |
| 9 | 43·80 | 1·036 | 45·37 | 16·29 | 19·59 | 2·78 | 83·0 | 42·28 | 20·4 | ·80 | ............ | ............ |
| 10 | 43·75 | 1·031 | 45·10 | 15·94 | 19·29 | 2·83 | 82·4 | 42·43 | 19·3 | ·83 | ............ | ............ |
| 11 | 43·90 | 1·059 | 46·49 | 15·19 | 19·28 | 3·06 | 79·0 | 41·45 | 19·1 | ·80 | ............ | ............ |
| | 43·98 | 1·053 | 46·32 | 13·42 | 16·44 | 3·544 | 81·1 | ....... | ...... | ...... | 216·1 | 264·8 |

TABLE V.—*Woodhouse and Rawson Lamps, 55 Volts (1st lot).*

| Lamp. | Volts. | Amperes. | Watts. | Candles. | | Watts per Spher. Cand. | Resistance. | | Stand'rd Reading. | Reduc'n Factor. | Candles per Elec. H P. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Mean Spherical. | Mean Horizont'l | | Cold. | Hot. | | | Spherical. | Horizont'l |
| 1 | 55·30 | 1·162 | 64·26 | 19·01 | 22·14 | 3·38 | 98· | 47·59 | 17·7 | 1·07 | ............ | ............ |
| 2 | 55·30 | ·871 | 48·16 | 12·42 | 15·08 | 3·87 | 132· | 63·49 | 10·8 | 1·15 | ............ | ............ |
| 3 | 55·20 | 1·162 | 61·14 | 20·06 | 21·39 | 3·19 | 102· | 47·50 | 17·6 | 1·11 | ............ | ............ |
| 4 | 55·15 | 1·057 | 58·29 | 17·99 | 21·27 | 3·21 | 108· | 52·18 | 17·2 | 1·05 | ............ | ............ |
| 5 | 55·40 | 1·000 | 55·40 | 13·97 | 16·31 | 3·96 | 118· | 55·40 | 12·3 | 1·14 | ............ | ............ |
| 6 | 55·30 | ·936 | 51·76 | 13·11 | 14·76 | 3·94 | 124· | 59·08 | 11·7 | 1·12 | ............ | ............ |
| 7 | 55·90 | ·914 | 51·09 | 15·53 | 19·45 | 3·29 | 132· | 61·16 | 15·5 | 1·00 | ............ | ............ |
| 8 | 56·05 | 1·025 | 57·45 | 15·05 | 18·28 | 3·81 | 116· | 54·68 | 14·0 | 1·07 | ............ | ............ |
| 9 | 55·95 | 1·125 | 62·94 | 18·43 | 22·01 | 3·41 | 106· | 49·73 | 18·5 | 1·00 | ............ | ............ |
| 10 | 56·00 | ·805 | 45·08 | 12·19 | 14·38 | 3·69 | 139· | 69·57 | 10·4 | 1·18 | ............ | ............ |
| 18 B | 55·25 | 1·004 | 55·47 | 14·33 | 17·41 | 3·87 | 115· | 55·03 | 12·0 | 1·19 | ............ | ............ |
| ............ | 55·53 | 1·006 | 55·82 | 15·64 | 18·68 | 3·605 | 117·3 | ........ | ...... | ...... | 200·0 | 249·6 |

## Table VI.—*Woodhouse and Rawson (2d lot).*

| Lamp. | Volts. | Amperes. | Watts. | Candles. | | Watts per Spher. Cand. | Resistance. | | Stand'rd Reading. | Reduc'n Factor. | Candles per Elec. H.P. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Mean Spherical. | Mean Horizont'l. | | Cold. | Hot. | | | Spherical. | Horizont'l |
| 30 | 55·00 | 1·167 | 64·18 | 18·52 | 22·73 | 3·46 | 100· | 47·13 | 17·18 | 1·08 | ............ | ............ |
| 31 | 55·05 | 1·182 | 65·07 | 17·28 | 20·93 | 3·76 | 102· | 46·57 | 18·48 | ·94 | ............ | ............ |
| 32 | 55·00 | 1·195 | 65·72 | 17·36 | 21·28 | 3·78 | 100· | 46·02 | 16·28 | 1·07 | ............ | ............ |
| 33 | 55·05 | 1·188 | 65·40 | 19·01 | 22·67 | 3·44 | 101· | 46·34 | 19·05 | 1·00 | ............ | ............ |
| 34 | 55·00 | 1·147 | 63·08 | 16·91 | 20·78 | 3·73 | 100· | 47·95 | 16·68 | 1·01 | ............ | ............ |
| 35 | 54·95 | 1·139 | 62·58 | 19·56 | 23·53 | 3·20 | 101· | 48·24 | 21·14 | ·93 | ............ | ............ |
| 36 | 55·00 | 1·191 | 65·50 | 21·41 | 25·98 | 3·05 | 99· | 46·18 | 22·13 | ·97 | ............ | ............ |
| 37 | 55·00 | 1·185 | 65·17 | 18·74 | 22·93 | 3·47 | 100· | 46·41 | 18·03 | 1·04 | ............ | ............ |
| 38 | 54·95 | 1·197 | 65·77 | 17·84 | 20·70 | 3·69 | 100· | 45·91 | 18·05 | ·99 | ............ | ............ |
| 39 | 55·00 | 1·186 | 65·23 | 16·33 | 19·74 | 3·99 | 99· | 46·37 | 15·50 | 1·05 | ............ | ............ |
| | 55·00 | 1·178 | 64·77 | 18·30 | 22·13 | 3·56 | 100·2 | ....... | ....... | ..... | 210·8 | 254·9 |

Note.—These lamps were marked 50 volts.

TABLE VII.—*White Lamps, 50 Volts.*

| Lamp. | Volts. | Amperes. | Watts. | Candles. | | Watts per Spher. Cand. | Resistance. | | Stand'rd Reading. | Reduc'n Factor. | Candles per Elec. H.P. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Mean Spherical. | Mean Horizont'l | | Cold. | Hot. | | | Spherical. | Horizont'l |
| 1 | 50·00 | 1·033 | 51·65 | 10·80 | 13·08 | 4·78 | ........... | 48·40 | 12·78 | ·85 | ........... | ........... |
| 2 | 50·00 | 1·005 | 50·25 | 10·97 | 13·20 | 4·58 | ........... | 49·75 | 12·93 | ·85 | ........... | ........... |
| 3 | 50·00 | ·928 | 46·40 | 9·09 | 11·08 | 4·05 | ........... | 53·88 | 10·75 | ·85 | ........... | ........... |
| 4 | 49·95 | 1·020 | 50·95 | 14·17 | 17·17 | 3·59 | ........... | 48·97 | 16·75 | ·85 | ........... | ........... |
| 5 | 50·00 | ·995 | 49·75 | 14·31 | 17·05 | 3·47 | ........... | 50·25 | 17·00 | ·84 | ........... | ........... |
| 6 | 50·00 | 1·047 | 52·35 | 14·64 | 17·55 | 3·57 | ........... | 47·76 | 17·38 | ·84 | ........... | ........... |
| 7 | 50·00 | 1·001 | 50·05 | 13·99 | 16·98 | 3·57 | ........... | 49·95 | 16·46 | ·85 | ........... | ........... |
| 8 | 50·00 | 1·025 | 51·25 | 11·69 | 14·23 | 4·38 | ........... | 48·78 | 14·13 | ·83 | ........... | ........... |
| 9 | 50·00 | 1·206 | 60·30 | 13·22 | 15·92 | 4·56 | ........... | 41·46 | 15·95 | ·83 | ........... | ........... |
| 10 | 49·95 | ·908 | 45·35 | 11·55 | 14·26 | 3·92 | ........... | 55·01 | 14·20 | ·81 | ........... | ........... |
| | 49·99 | 1·017 | 50·83 | 12·44 | 15·05 | 4·05 | ...... | ........ | ........ | ...... | 182·6 | 220·9 |

* An error was made in measuring resistance cold, which was not discovered in time for correction.

## Table VIII.—*Weston Lamps, $110\frac{1}{2}$ Volts.*

| Lamp. | Volts. | Amperes. | Watts. | Candles. | | Watts per Spher. Cand. | Resistance. | | Stand'rd Reading. | Reduc'n Factor. | Candles per Elec.H.P. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Mean Spherical. | Mean Horizont'l | | Cold. | Hot. | | | Spherical. | Horizont'l |
| 1 | 111·3 | ·519 | 57·76 | 17·49 | 19·36 | 3·30 | ............ | 214·5 | 20·10 | ·87 | ............ | ............ |
| 2 | 111·0 | ·530 | 58·83 | 14·16 | 15·37 | 4·15 | ............ | 209·4 | 16·72 | ·85 | ............ | ............ |
| 3 | 111·3 | ·502 | 55·87 | 14·28 | 15·77 | 3·82 | ............ | 221·7 | 16·32 | ·87 | ............ | ............ |
| 4 | 111·6 | ·546 | 60·93 | 12·70 | 13·81 | 4·79 | ............ | 204·4 | 16·20 | ·78 | ............ | ............ |
| 5 | 111·5 | ·537 | 59·87 | 16·01 | 17·53 | 3·74 | ............ | 207·6 | 18·18 | ·88 | ............ | ............ |
| 6 | 111·5 | ·501 | 55·86 | 11·25 | 12·18 | 4·96 | 402· | 222·6 | 14·00 | ·81 | ............ | ............ |
| 7 | 111·5 | ·543 | 60·54 | 18·32 | 20·10 | 3·30 | 414· | 205·3 | 21·95 | ·83 | ............ | ............ |
| 8 | 111·5 | ·523 | 58·31 | 20·23 | 22·51 | 2·88 | 423· | 213·2 | 21·88 | ·92 | ............ | ............ |
| 9 | 111·4 | ·530 | 59·04 | 16·53 | 17·97 | 3·57 | 409· | 210·2 | 21·90 | ·75 | ............ | ............ |
| 10 | 111·5 | ·529 | 58·98 | 19·08 | 20·82 | 3·09 | 421· | 210·8 | 22·15 | ·86 | ............ | ............ |
| 11 | 111·4 | ·513 | 57·14 | 16·16 | 17·86 | 3·53 | 409· | 217·2 | 21·04 | ·77 | ............ | ............ |
| 12 | 111·5 | ·553 | 61·66 | 22·26 | 24·45 | 2·77 | 408· | 201·6 | 25·68 | ·87 | ............ | ............ |
| 13 | 111·5 | ·531 | 59·20 | 16·27 | 18·13 | 3·63 | 407· | 210·0 | 20·30 | ·80 | ............ | ............ |
| 14 | 111·4 | ·549 | 61·15 | 19·14 | 21·31 | 3·19 | 409· | 202·9 | 24·65 | ·78 | ............ | ............ |
| 15 | 111·4 | ·491 | 54·69 | 9·78 | 10·45 | 5·59 | 408· | 226·9 | 11·97 | ·82 | ............ | ............ |
| 16 | 111·4 | ·513 | 57·14 | 15·03 | 16·43 | 3·80 | 399· | 217·2 | 18·12 | ·83 | ............ | ............ |
| 17 | 111·5 | ·521 | 58·09 | 12·23 | 14·08 | 4·75 | 404· | 214·0 | 15·35 | ·80 | ............ | ............ |
| 18 | 111·4 | ·540 | 60·15 | 16·71 | 17·95 | 3·60 | 405· | 206·3 | 20·97 | ·80 | ............ | ............ |
| 19 | 111·4 | ·561 | 62·49 | 20·30 | 22·93 | 3·07 | 402· | 198·6 | 27·95 | ·73 | ............ | ............ |
| 20 | 111·4 | ·562 | 62·60 | 19·44 | 20·88 | 3·22 | 392· | 198·2 | 21·68 | ·90 | ............ | ............ |
| 21 | 111·4 | ·528 | 58·81 | 17·02 | 18·03 | 3·45 | 409· | 211·0 | 19·65 | ·87 | ............ | ............ |
| 23 | 111·5 | ·536 | 59·76 | 17·44 | 19·92 | 3·42 | 400· | 208·0 | 22·68 | ·77 | ............ | ............ |
| 24 | 111·3 | ·530 | 58·99 | 16·08 | 17·71 | 3·77 | 421· | 210·0 | 18·02 | ·89 | ............ | ............ |
| | 111·42 | ·530 | 59·04 | 16·43 | 18·07 | 3·713 | 407·9 | ........ | ...... | ...... | 209·8 | 230·7 |

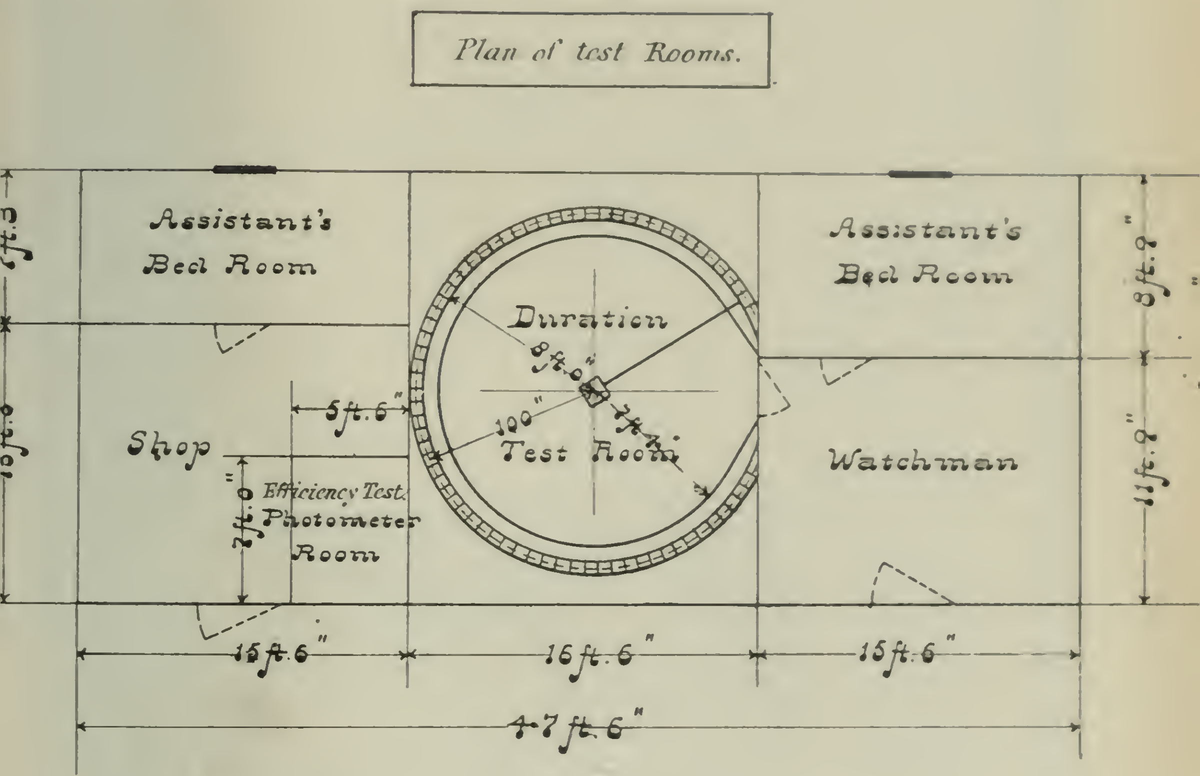
## Table IX.—*Weston Lamps, 70 Volts.*

| Lamp. | Volts. | Amperes. | Watts, | Candles. | | Watts per Spher. Cand. | Resistance. | | Stand'rd Reading. | Reduc'n Factor. | Candles per Elec. H.P. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Mean Spherical. | Mean Horizont'l | | Cold. | Hot. | | | Spherical. | Horizont'l |
| 51 | 70·2 | ·963 | 67·60 | 14·53 | 16·22 | 4·65 | 152· | 72·90 | 17·35 | ·84 | ........... | ........... |
| 54 | 70·4 | ·959 | 67·51 | 14·46 | 15·73 | 4·66 | 149· | 73·41 | 17·33 | ·83 | ........... | ........... |
| 55 | 70·4 | 1·002 | 70·51 | 17·11 | 18·83 | 4·12 | 144· | 70·26 | 20·80 | ·82 | ........... | ........... |
| 56 | 70·4 | ·969 | 68·21 | 15·07 | 16·96 | 4·52 | 148· | 72·65 | 18·10 | ·83 | ........... | ........... |
| 58 | 70·5 | ·952 | 67·11 | 16·95 | 18·67 | 3·96 | 153· | 71·05 | 19·80 | ·86 | ........... | ........... |
| 59 | 70·4 | ·944 | 66·45 | 16·01 | 18·12 | 4·14 | 152· | 71·58 | 19·78 | ·81 | ........... | ........... |
| 61 | 70·3 | ·969 | 68·12 | 13·06 | 14·23 | 5·21 | 153· | 72·55 | 15·48 | ·84 | ........... | ........... |
| 62 | 70·4 | ·971 | 68·35 | 14·42 | 16·03 | 4·74 | 148· | 72·50 | 18·02 | ·80 | ........... | ........... |
| 63 | 70·4 | ·984 | 69·27 | 14·85 | 16·93 | 4·66 | 147· | 71·51 | 18·35 | ·81 | ........... | ........... |
| 64 | 70·4 | ·962 | 67·72 | 15·32 | 16·76 | 4·42 | 149· | 73·18 | 18·00 | ·85 | ........... | ........... |
| ......... | 70·4 | ·968 | 68·09 | 15·18 | 16·85 | 4·51 | 150· | ......... | 18·30 | ...... | 166·3 | 184·6 |

## TEST FOR DURATION.

For the duration test proper the three rooms of the Brush exhibit during the exhibition were utilized. The arrangements are shown in Fig. 13. The lamps were placed in boxes arranged in a circle in the middle room, which was securely boarded up, with the exception of one door opening into the watchman's room. This door was securely locked and sealed, except when measurements or adjustments were being made. A glass pane set in it (Fig. 14) allowed of inspection of the lamps when the door was closed. On the opposite side of the duration test room was a shop in which all necessary electrical work was done. In a corner was the photometer room, containing the photometer used in the efficiency measurements (Figure 6). The two rooms marked as assistants' bed rooms were permanently occupied by the assistants connected with the test, Mr. A. L. Church, who was in charge in absence of members of the committee, and Mr. C. E. Billberg. The exhibition building around the three rooms was well lighted by extra lamps in circuit, and the whole was under the inspection of a watchman. When the committee finished their daily work in the duration test room, the door was locked and sealed in the presence of one of the committee and remained closed until the next day, when the seal was examined before the room was opened. It was always found intact. While the room was closed, inspection of the lamps was made through the glass set in the door. These inspections were made every half hour, and whenever a lamp was observed to be out the time was recorded. The lamp was examined the next time the room was opened, and removed if found to be broken. It was feared that lamps might be accidentally broken, and provision was made in the code for replacing such lamps by others. In order to avoid breakage the lamps were never touched except to adjust their position in the socket, or to remove dust which had settled on them. Only one lamp (Stanley No. 12), was accidentally broken in the test, and this occurred while making a connection, by accidentally touching its leading wire to the binding post of the next lamp, giving the lamp 96 volts instead of the 44 required. When the room was open, no one not connected with the test was allowed to enter it unless accompanied by a member of the committee.

The arrangements in the duration test room may be understood from Figs. 15 and 16, the former being from a drawing and the latter being a longitudinal section through the lamp boxes. The lamps were




Test of Incandescent Electric Lamps.

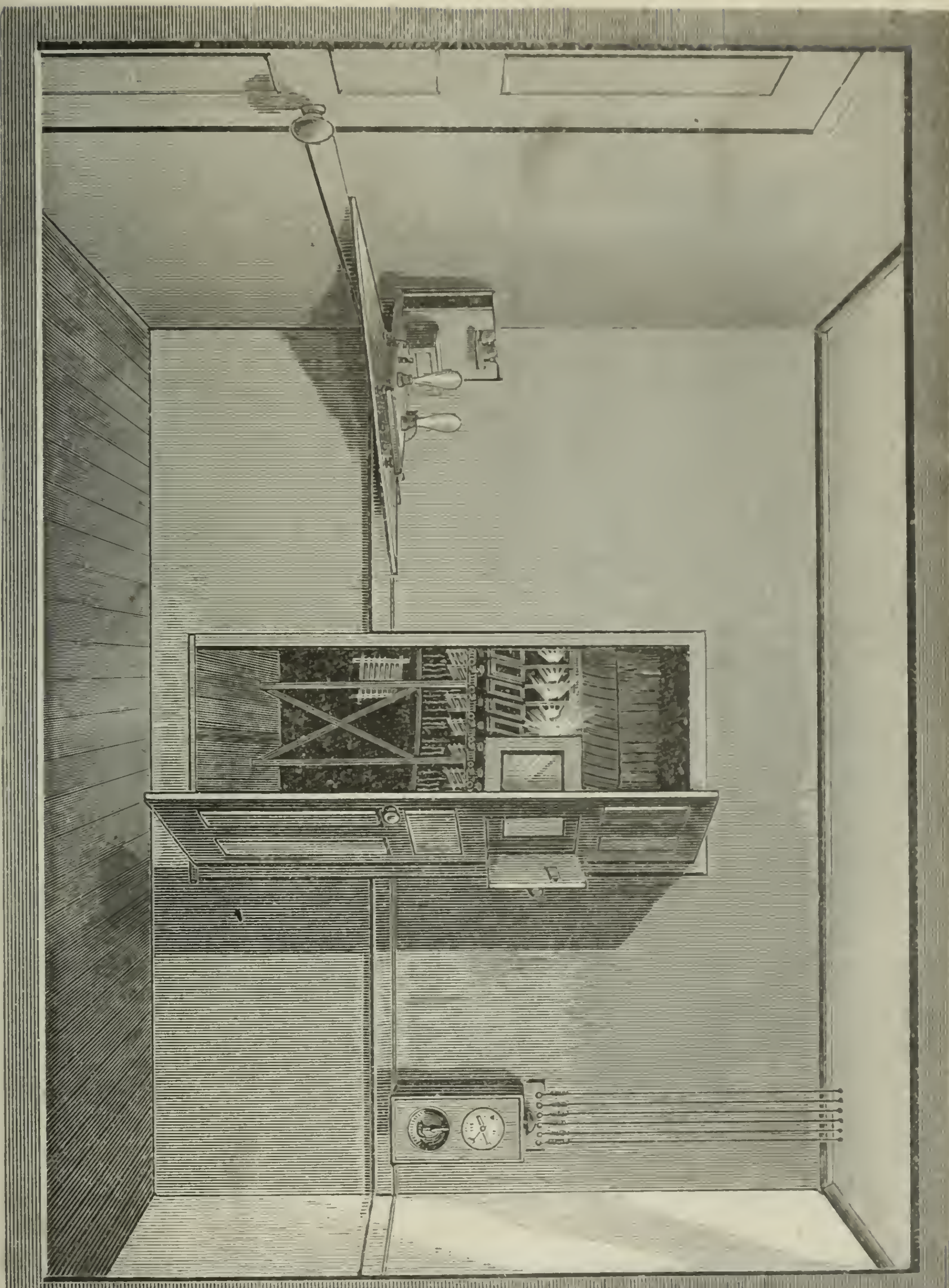
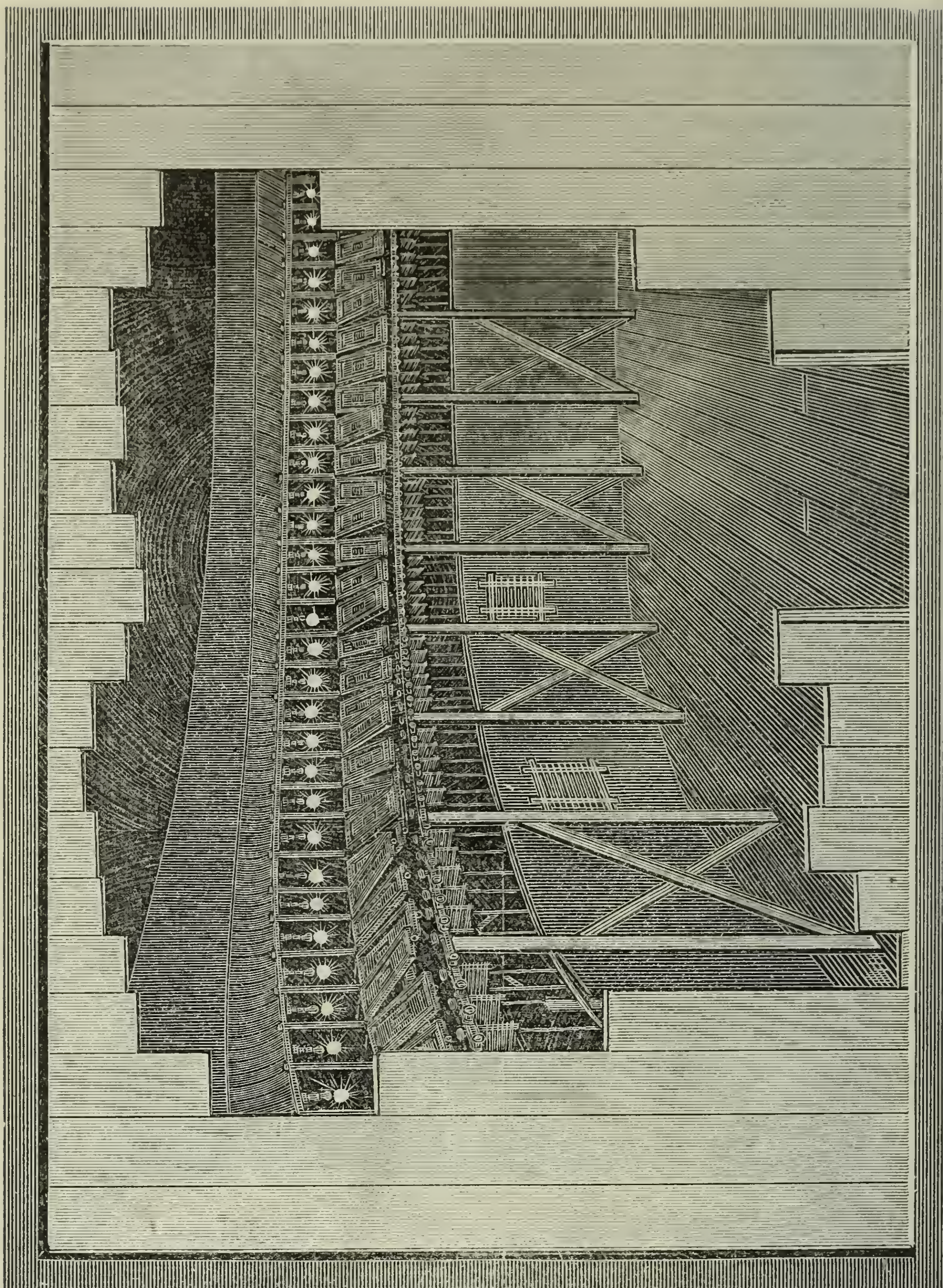
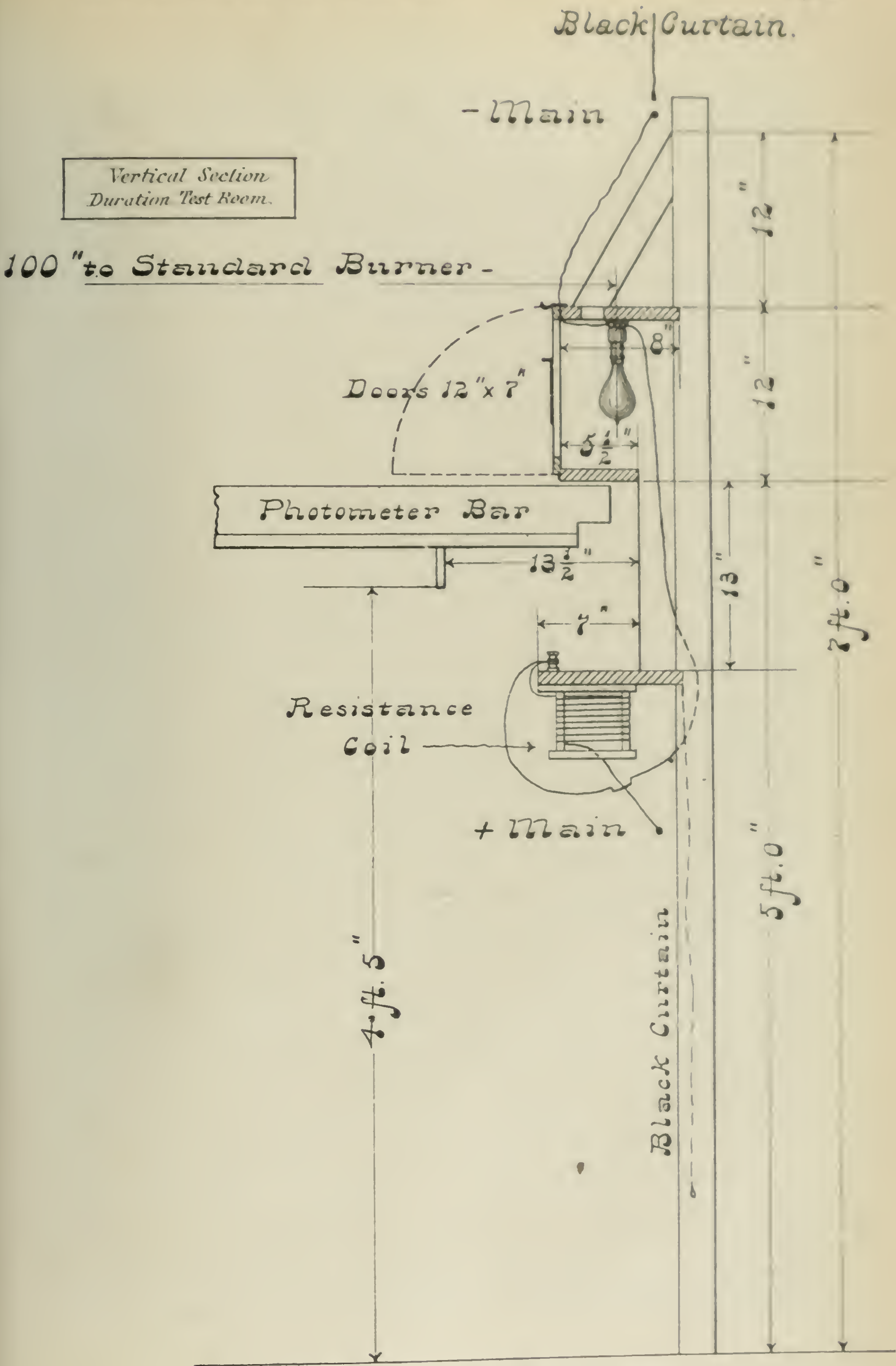


FIG. 14.—Test room from Watchman's room.






Test of Incandescent Electric Lamps.

arranged in a circle of one hundred inches radius, the centre of which was occupied by the slit of the Methven burner. This distance was carefully measured and verified. The circle contained boxes for seventy-one lamps, each box being eight inches wide. The lamp sockets were screwed to brass nipples on the hundred-inch curve. Each box had a door which opened inward and downward. In Fig. 15 the doors are down, in Fig. 17 they are closed. The details of the boxes are shown in Fig. 16. The lamp is seen in its box with the door closed. The back of the box is open, the escape of light in that direction being deadened by reflection on the blackened wall of the room, and still further prevented from affecting the photometer disc by curtains above and below the lamps. Each box contained an opening in its top of two inches wide and six inches in length, for the purpose of assisting in carrying off hot air. The rear portion of the lower shelf was also cut away to assist in producing a vertical air current, when the box was closed. The middle and lower shelves of the plan were connected by a blackened sheet of heavy pasteboard. The doors and the partitions separating the boxes were made of sheet zinc. Each lamp circuit lay in a vertical plane. One of the lamp leads passed from the upper main down through a slot in the upper shelf into the box to the socket. The other passed through the opening in the lower part of the box down behind the pasteboard to a binding post on the lower shelf. These posts were placed on a strip of wood, not shown in the figure, covered with several coats of shellac, and fastened by pins to the front edge of the shelf. This strip was kept wiped clean from dust or anything that might cause leakage over its surface. To the binding post was also connected one end of the adjustable German-silver resistance, the other end being soldered to the lower main. The reels were of different sizes, the largest being about twelve inches square and two inches wide. Cotton insulated German-silver wire was used, the size varying from 22 to 26, American gauge. The turns were loosely wound on the reel, and the air cooling was in all cases sufficient, no charring of the insulation or short circuiting of the wire occurring. Some of the lamps required as much as three hundred feet of wire to procure adjustment of potential. The spare wire of each reel was wound on a spool fastened to the front side of the shellaced strip. The mains were supported by porcelain insulators, and after the leading wires had been soldered were wrapped with rubber tape. The inside of the room being lampblacked throughout, a slight leak was sometimes

perceptible from the upper main to the ground, but the insulation resistance between the mains through the lamp sockets and between the upper main and the brass terminals was tried both before and after the test and found to be practically infinite, no deflection being perceptible with an E. M. F. and galvanometer, capable of indicating thirty megohms.

The duration test room was ventilated by large holes, cut both in the roof and in the floor. The temperature of the room averaged about 3°C. above that of the air in the building. The temperature of the boxes was frequently tested and found to be about 16°C. above the rest of the room, rising to 18° when the doors were closed. The highest temperature of the room during the test was 33·5°C.

The photometer arrangements are shown in Fig. 17, the door of the central box carrying the Methven standard being shown open. Each box door contained a slot cut to the size of the carbon of the lamp in the box. This slot was covered by a movable shutter. It was found, however, that as a rule the reflection from the walls back of the boxes was inappreciable on the photometer and measurements were generally made with doors down, it being thought better that any extra light should be in favor of the lamp, than that risk should be run of cutting off any light by errors in size or shape of the slot or in displacement of the door due to the continual handling.

The general method of daily work was as follows: The forenoon was devoted to calibration of the potential galvanometer, to adjustments of potential of the lamps by means of the German-silver resistances, and to the calculation and recording of the previous day's work. The photometric measurements were made in the afternoon. This was varied to suit circumstances. Three persons took part in each observation. The lamp was first put in circuit with the current galvanometer. This was done by disconnecting the lower leading wire of the lamp from the binding screw and connecting it to one of the leads of the current galvanometer by a connector, to which was also fastened one of the potential leads, the other being on the upper main. The return lead from the current galvanometer was clamped to the binding post on the shellaced strip. The tangent galvanometer and its leads were thus in circuit with the lamp, but as the resistance of both was less than a tenth of an ohm, the increased resistance of the circuit was not more than $\frac{1}{500}$ of the lowest resistance lamp tested. After the connections were completed ten photometric measurements were made

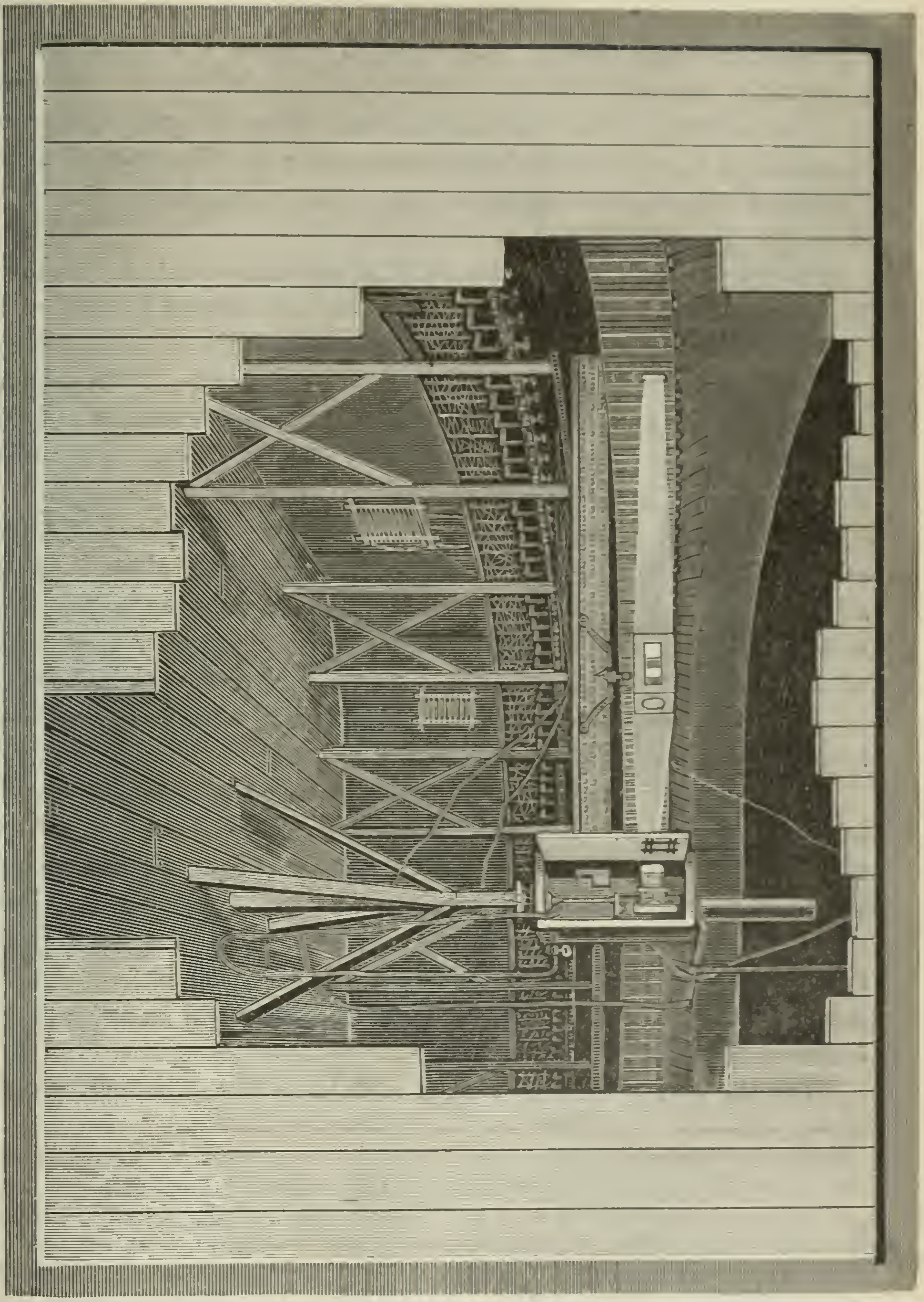


Fig. 17—Photometer arrangements—duration test room.

and the mean taken as the candle-power. Two observers read the galvanometers, a double reading of the potential galvanometer being made with the currents in the tangent in each direction. As soon as the electrical measurements were finished a signal was made and the connections were shifted to the next lamp. Each observation was, therefore, the average of ten photometric, four potential and two current readings. The observations were first made with the potential under control of the automatic regulator, but it was soon found necessary to depend on hand regulation during measurements.

A series of calibrations of the potential galvanometer had been made before the test for duration commenced. A resistance of 100,000 ohms was used in this test in the galvanometer circuit for all potentials of seventy volts or less, and 150,000 for higher potentials. The preliminary series gave a constant of 3·615 for 100,000 and 5·436 for 150,000 at the mean temperature of the room. The calibrations made during the test and the constants used day by day are given in Table X.

The observations were calculated so far as was possible at the time of observation, each observer making his own calculation. As the average time of observation on each lamp was three minutes, this work was very much hurried. Tabulated forms were generally used. The whole of the day's work was gone over again from the original records in the evening and the next morning, and results were finally reviewed by another computer after the test was finished.

In reviewing the results of the test, the committee note discrepancies in the candle-power. From the continuous nature of the test, no repetition of the work was possible, and the discrepancies referred to were shown to be such, only by observations on subsequent days. Under these circumstances no verification could be made. In order to facilitate comparison they feel justified in rejecting the observations of April 25, 27, 28, 29* and May 15 and 25,† as not in accord with the others of the series.

After the test, the discoloration of each lamp was estimated by com-

* Marked magnetic disturbances were reported from the magnetic observatories at Toronto and at Los Angeles, Cal., between April 25th and 29th.

† Through the courtesy of Prof. Hilgard, Supt. of the U. S. Coast and Geodetic Survey, the committee have since the termination of the test received a complete set of tracings recorded by the bi-filar magnetometer at the Magnetic Observatory at Los Angeles, Cal. These tracings show marked variations of H. on April 26th, 27th, 28th, and May 25th, which might partially account for the discrepancies on those days.

TABLE X.—*Results of Calibrations of Potential Galvanometer.*

| Date. | Constant for 100000 | Constant for 150000 | Constants used 100000 | Constants used 150000 |
|---|---|---|---|---|
| 11 | 3·619 | 5·428 | …….. | …… |
| 12 | …….. | …….. | …….. | …… |
| 13 | …….. | …….. | 3·615 | 5·44 |
| 14 | 3·620 | …….. | 3·615 | 5·44 |
| 15 | 3·615 | …….. | 3·615 | 5·44 |
| 16 | 3·612 | …….. | 3·615 | 5·44 |
| 17 | 3·625 | …….. | 3·615 | 5·44 |
| 18 | 3·620 | …….. | 3·615 | 5·44 |
| 19 | 3·626 | 5·457 | 3·615 | 5·44 |
| 20 | 3·615 | 5·436 | 3·615 | 5·44 |
| 21 | 3·620 | …….. | 3·615 | 5·44 |
| 22 | 3·613 | …….. | 3·615 | 5·44 |
| 23 | 3·611 | …….. | 3·615 | 5·44 |
| 24 | 3·602 | 5·432 | 3·615 | 5·44 |
| 25 | 3·611 | …….. | 3·615 | 5·54 |
| 26 | …….. | …….. | 3·615 | 5.44 |
| 27 | 3·596 | …….. | 3·600 | 5·43 |
| … | 3·605 | 5·427 | …….. | …… |
| 28 | 3·606 | …….. | 3·61 | 5·43 |
| 29 | 3·609 | …….. | 3·61 | 5·43 |
| 30 | 3·607 | 5·439 | 3·61 | 5·43 |
| … | ….. .. | 5·431 | …….. | …… |
| May. | | | | |
| 1 | 3·607 | 5·398 | 3·61 | 5·43 |
| 1 | 3·602 | 5·418 | …….. | …… |
| … | …….. | 5·423 | …….. | …… |
| 2 | 3·614 | 5·434 | 3·61 | 5·43 |
| 3 | …….. | …….. | 3·61 | 5·43 |
| 4 | 3·602 | 5·412 | 3·61 | 5·43 |
| 5 | 3·616 | 5·431 | 3·61 | 5·43 |
| 6 | 3·603 | 5·416 | 3·61 | 5·43 |
| May. | | | | |
| 7 | 3·597 | 5·396 | 3·60 | 5·41 |
| 8 | 3·586 | 5·388 | 3·59 | 5·40 |
| 8 | 3·590 | 5·399 | …… | …… |
| 9 | 3·604 | 5·417 | 3·60 | 5·41 |
| 10 | 3·596 | …….. | 3·61 | 5·42 |
| 11 | 3·600 | 5·405 | 3·60 | 5·41 |
| 12 | 3·603 | 5·432 | 3·61 | 5·42 |
| 13 | 3·610 | 5·422 | 3·61 | 5·42 |
| … | 3·601 | 5·424 | …… | …… |
| 14 | 3·604 | 5·408 | 3·61 | 5·42 |
| … | 3·611 | 5·422 | ….. | …… |
| 15 | 3·612 | 5·415 | 3·61 | 5·41 |
| 16 | 3·607 | 5·416 | 3·61 | 5·41 |
| 17 | …….. | …….. | 3·61 | 5·41 |
| 18 | 3·597 | 5·412 | 3·60 | 5·41 |
| … | 3·601 | 5·412 | …… | …… |
| 19 | 3·605 | 5·412 | 3·605 | 5·41 |
| … | 3·608 | 5·427 | …… | …… |
| 20 | 3·598 | 5·412 | 3·60 | 5·41 |
| 21 | 3·591 | 5·402 | 3·60 | 5·41 |
| … | 3·597 | 5·416 | …… | …… |
| 22 | 3·585 | 5·393 | 3·59 | 5·41 |
| … | 3·595 | 5·411 | …… | …… |
| 23 | 3·585 | …….. | 3·59 | 5·40 |
| … | 3·586 | …….. | …… | …… |
| 24 | 3·591 | 5·406 | 3·59 | 5·40 |
| 25 | 3·601 | …….. | 3·59 | 5·40 |
| … | 3·593 | 5·388 | …… | …… |
| … | …….. | 5·408 | …… | …… |
| 28 | …….. | 5·390 | …… | …… |

parison with six lamps taken as standards. Number one showed the least discoloration, and number six the greatest, the latter having its carbon destroyed by too high a potential.

The committee present the following summary of the results (Tables XI–XVII): Whenever the candle-power was observed at too high or too low potential, the former is reduced to what it would have been at normal potential by such an allowance as seems proper, the general rules being given for each lot of lamps. These values are derived from the data given in the tables of efficiency and duration, and are believed to be substantially correct.

EDISON. (TABLE XI.)

In allowing for the potential being other than normal, one volt is assumed to cause a difference of mean horizontal intensity of one candle. The whole lot of lamps behaved with great uniformity, there being in all a gradual increase of resistance throughout the test.

STANLEY-THOMPSON. (TABLES XII, XIII.)

The same allowance is made for candle-power per volt with 96-volt lamps as with the Edison. In correcting the 44-volt lamps, an allowance of one and a half spherical candles is made for one volt. The test of the latter was not perfectly satisfactory, as most of the lamps were connected two in series. The only adjustment of potential possible was the sum of the potentials of the two lamps, and as soon as the resistance of the lamps began to change, one of each pair was at a higher potential than normal, the other lower. As soon as possible the lamps were placed in separate circuits. The average potential of each lamp during its life, taken from the daily observations of potential is given in the table to assist in interpreting the results. Number 3 lamp in particular was tested at so high a potential that it was thought best to introduce another, and number 12, which had never been measured for efficiency, was tested for life, but was accidentally destroyed after 307 hours.

WOODHOUSE AND RAWSON. (TABLE XVI.)

The allowance for these lamps is one and a half spherical candle per volt, that being about the average of ten lamps tested at two different potentials. Most of the first lot tested were connected two in series, and the same objection holds here as with the Stanley-Thompson

lamps. The committee were very willing, therefore, to test a second lot of lamps, which were placed in separate circuits from the start. The resistance of this second lot gradually decreased for three days, the candle-power rising, and then falling as the resistance increased. All the lamps were much discolored.

### WHITE. (TABLE XV.)

This set of lamps changed greatly in their candle-power. Every lamp decreased in resistance, the average decrease being two and a half ohms in about one hundred hours, the candle-power increasing greatly. The resistance then began to increase and the candle-power to fall off, but after 250 hours the candle-power was still higher than in the preliminary efficiency test. In correcting, the allowance of one and a half spherical candles per volt is made.

### WESTON ($110\frac{1}{2}$ VOLT). (TABLE XVI.)

The action of these lamps is shown by the tables of daily observations. As predicted by Mr. Weston, they increased rapidly in resistance at first, the candle-power falling greatly. The correction of one spherical candle per volt is assumed in correcting these lamps.

### WESTON (70 VOLT). (TABLE XVII.)

A difficulty was experienced with all the Weston lamps in getting the point of 0° lat. 0° long. exactly towards the photometer. Owing to the peculiar oblique position of the major axis of the curve of horizontal illumination, in relation to the plane of the carbon shanks, a slight rotation of the lamp in its socket materially affected the photometer reading. The fall of candle-power in number 62 may have been partially due to this, as the attempt was made on May 5th to adjust it. The increase of resistance, however, shows a deterioration in the lamp as well. The resistance of these lamps as a whole remained about constant, the changes being but slight in either direction, The correction allowed is one and three-tenths spherical candle per volt, determined by measurements of a lamp at different potentials.

The daily records of the lamps are appended (page 56, *et seq*). The calculations have been carefully revised. The first line of each lamp record contains the results of the preliminary efficiency measurements. The entries of candles under date of April 11, are the results of photo-

meter readings at the beginning of the test. The resistances had all been adjusted previously but it was thought desirable to check with the photometer that no lamp might be forced by an accidental high potential. The asterisks against the dates show that the observations made on those days are rejected as not in accordance with others of the series. The time is recorded in hours and minutes, to the nearest quarter of an hour.

*Edison Lamps.* (TABLE XI.)

| Lamp. | Hours of test. | Life of lamp. | Candles. Efficiency measurements. Spher'l. | Horiz'l. | Candles. Spher. | Horizontal. | | Discoloration. |
|---|---|---|---|---|---|---|---|---|
| 1 | 1,066 | Survived. | 15·3 | 18·8 | 9·3 | 11·4 | After 1006 hours. | 3 |
| 2 | 1,065 | '' | 13·6 | 16·7 | 9·9 | 12·2 | '' '' '' | 2 |
| 3 | '' | '' | 14·2 | 17·2 | 9·7 | 11·7 | '' '' '' | 2 |
| 4 | '' | '' | 15·0 | 18·6 | 9·6 | 11·9 | '' '' '' | 2½ |
| 5 | '' | '' | 15·7 | 19·5 | 10·5 | 13·0 | '' '' '' | 2½ |
| 6 | '' | '' | 14·0 | 17·1 | 10·3 | 12·7 | '' '' '' | 2½ |
| 7 | '' | '' | 11·0 | 17·6 | 9·3 | 11·7 | '' '' '' | 2½ |
| 8 | '' | '' | 16·0 | 19·4 | 10·1 | 12·2 | '' '' '' | 3 |
| 9 | '' | '' | 14·4 | 17·7 | 9·7 | 11·9 | '' '' '' | 2½ |
| 10 | '' | '' | 14·0 | 17·7 | 9·8 | 12·4 | '' '' '' | 2 |
| 11 | '' | '' | 16·1 | 20·3 | 9·8 | 12·4 | '' '' '' | 3 |
| 12 | '' | '' | 13·1 | 16·7 | 10·3 | 13·1 | '' '' '' | 2 |
| 13 | '' | '' | 14·9 | 18·3 | 10·1 | 12·4 | '' '' '' | 2½ |
| 14 | '' | '' | 15·1 | 19·0 | 9·3 | 11·7 | '' '' '' | 3 |
| 15 | '' | 295 | 15·1 | 19·0 | 12·4 | 15·6 | '' 260 '' | 2 |
| 16 | '' | Survived. | 15·5 | 19·6 | 9·3 | 11·7 | '' 1006 '' | 2½ |
| 17 | '' | '' | 16·0 | 20·3 | 8·9 | 11·3 | '' '' '' | 3 |
| 18 | '' | '' | 15·0 | 18·5 | 9·0 | 11·1 | '' '' '' | 2½ |
| 19 | '' | '' | 15·4 | 18·8 | 9·5 | 11·6 | '' '' '' | 2½ |
| 20 | '' | '' | 15·2 | 18·9 | 9·0 | 11·2 | '' '' '' | 2 |

*Stanley-Thompson Lamps, 96 Volts.* (TABLE XII.)

| Lamp. | Hours of test. | Life of lamp. | Candles in efficiency tests. Spher'l. | Horiz'l. | Candles. Spher. | Horizontal. | | Discoloration. |
|---|---|---|---|---|---|---|---|---|
| 26 | 1,065 | 78 | 12·8 | 15·4 | 12·3 | 14·7 | After 53 hours. | 2 |
| 28 | '' | 233 | 16·7 | 19·3 | 9·2 | 11·0 | '' 218 '' | 3 |
| 29 | '' | 176 | 16·2 | 19·1 | 10·1 | 11·3 | '' 172 '' | 3½ |
| 30 | '' | Survived. | 12·7 | 15·4 | 6·2 | 7·5 | '' 1000 '' | 3 |
| 33 | '' | 257 | 14·0 | 16·8 | 8·3 | 9·8 | '' 241 '' | 2 |
| 34 | '' | 525 | 13·9 | 16·6 | 8·5 | 10·2 | '' 502 '' | 3½ |
| 35 | '' | 100 | 13·2 | 16·2 | 10·4 | 12·7 | '' 100 '' | 2 |
| 36 | '' | 301 | 16·3 | 19·4 | 8·4 | 10·0 | '' 241 '' | 3½ |
| 37 | '' | 882 | 13·4 | 16·1 | 6·5 | 7·8 | '' 837 '' | 2½ |
| 41 | '' | 683 | 11·9 | 14·3 | 7·9 | 9·5 | '' 670 '' | 2½ |

*Stanley-Thompson Lamps, 44 Volts.* (TABLE XIII.)

| Lamp. | Hours of test. | Life of lamp. | Average Potent'l. | Candles in efficiency test. | | Candles. | | | Discoloration. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Spher'l. | Horiz'l. | Spher. | Horizontal. | | |
| 1 | 1,065 | 309 | 43·60 | 11·8 | 14·6 | 6·6 | 7·8 | Af'r 290 h. | 4½ |
| 2 | " | 143 | 41·40 | 10·4 | 12·5 | 10·2 | 12·3 | " 101 " | 3½ |
| 3 | " | 137 | 46·85 | 16·0 | 19·7 | 8·0 | 9·8 | " 101 " | 4½ |
| 4 | " | 178 | 43·95 | 14·2 | 17·6 | 9·0 | 11·2 | " 173 " | 4½ |
| 6 | " | 288 | 43·85 | 10·4 | 17·1 | 6·8 | 8·3 | " 280 " | 3½ |
| 7 | " | 303 | 42·40 | 12·6 | 15·4 | 9·5 | 11·6 | " 283 " | 4 |
| 8 | 1,047 | Survived. | 43·65 | 10·8 | 13·2 | 5·4 | 6·6 | " 987 " | 4 |
| 9 | 1,065 | 40 | .............. | 16·6 | 19·9 | ........... | ........... | ................ | 2½ |
| 10 | " | 206 | 43·20 | 16·3 | 19·7 | 10·0 | 12·1 | Af r 202 h. | 3½ |
| 11 | " | 275 | 44·10 | 15·3 | 19·4 | 6·5 | 8·3 | " 265 " | 4½ |
| 12 | 865 | 307* | .............. | 11·0† | .............. | 9·2 | ....... ... | " 307 " | 6 |

* Accidentally destroyed. † Standard reading. No reduction factor.

*Woodhouse and Rawson Lamps.* (TABLE XIV.)

| Lamp. | Hours of Test. | Life of lamp. | Average Potent'l. | Candles in efficiency tests. | | Candles. | | | Discoloration. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Spher'l. | Horiz'l. | Spher. | Horizontal. | | |
| 1 | 1,065 | 41 | .............. | 18·5 | 21·5 | ........... | ........... | ................ | 3½ |
| 3 | 1,065 | 214 | 55·60 | 19·7 | 24·0 | 13.0 | 15·9 | Af'r 213 h. | 4½ |
| 4 | 1,065 | 203 | 54·90 | 17·8 | 21·0 | 12·3 | 14·5 | " 170 " | 4½ |
| 5 | 1,065 | 440 | 54·55 | 13·3 | 15·6 | 10·4 | 12·2 | " 289 " | 4½ |
| 6 | 1,065 | 395 | 54·15 | 12·7 | 14·4 | 10·9 | 12·3 | " 289 " | 4 |
| 7 | 1,065 | 423 | 55·80 | 14·2 | 17·7 | 10·1 | 12·6 | " 289 " | 4½ |
| 8 | 1,065 | 118 | 55·75 | 13·6 | 16·5 | 12·8 | 15·5 | " 78 " | 3 |
| 9 | 1,065 | 716 | 55·00 | 17·0 | 20·4 | 6·6 | 7·8 | " 716. " | 5 |
| 10 | 1,065 | 69 | 55·20 | 10·8 | 12·7 | 12·4 | 14·6 | " 32 " | 2½ |
| 18B | 1,065 | 278 | 55·15 | 14·0 | 16·9 | 13·3 | 16·1 | " 266 " | 3½ |
| 30 | 332 | Survived. | .............. | 18·5 | 22·7 | 14·8 | 18·3 | " 273 " | 4 |
| 31 | 332 | 227 | .............. | 17·2 | 20·9 | 14·5 | 17·5 | " 200 " | 4 |
| 32 | 332 | Survived. | .............. | 17·4 | 21·3 | 13·9 | 17·1 | " 272 " | 3½ |
| 33 | 331 | " | .............. | 19·0 | 22·7 | 14·6 | 17·4 | " 272 " | 4 |
| 34 | 331 | 235 | .............. | 16·9 | 20·8 | 16·5 | 20·3 | " 200 " | 3 |
| 35 | 331 | 272 | .............. | 19·6 | 23·5 | 13·5 | 16·2 | " 272 " | 3½ |
| 36 | 331 | Survived. | .............. | 21·4 | 26·0 | 12·4 | 15·0 | " 272 " | 4 |
| 37 | 331 | 177 | .............. | 18·7 | 22·9 | 17·6 | 21·5 | " 151 " | 3½ |
| 38 | 331 | 224 | .............. | 17·9 | 20·8 | 17·0 | 19·7 | " 200 " | 4½ |
| 00 | 331 | 213 | .............. | .............. | 20·0* | 15·3* | ........... | " 198 " | 4 |

*Standard reading. No reduction factor.

## *White Lamps.* (TABLE XV.)

| Lamp. | Hours of test. | Life of lamp. | Candles in efficiency tests. | | Candles. | | | Discoloration. |
|---|---|---|---|---|---|---|---|---|
| | | | Spher'l. | Horiz'l. | Spher. | Horizontal. | | |
| 1 | 312 | Survived. | 10·8 | 13·1 | 15·9 | 19·2 | After 253 hrs. | 3½ |
| 2 | 312 | " | 11·0 | 13·2 | 14·3 | 17·2 | " 252 " | 2½ |
| 3 | 312 | " | 9·1 | 11·1 | 12·1 | 14·8 | " 252 " | 3 |
| 4 | 311 | " | 14·2 | 17·2 | 14·6 | 17·7 | " 252 " | 3 |
| 5 | 311 | " | 14·3 | 17·1 | 12·1 | 14·4 | " 252 " | 4 |
| 6 | 311 | 229 | 14·6 | 17·6 | 15·4 | 18·5 | " 227 " | 4 |
| 7 | 311 | 160 | 14·0 | 17·0 | 15·7 | 19·0 | " 132 " | 3½ |
| 8 | 311 | Survived. | 11·7 | 14·2 | 13·2 | 16·1 | " 250 " | 3 |
| 9 | 311 | 165 | 13·2 | 15·9 | 15·6 | 18·7 | " 132 " | 2½ |
| 10 | 310 | Survived. | 11·6 | 14·3 | 11·3 | 13·9 | " 250 " | 3 |

## *Weston Lamps, 110½ Volts.* (TABLE XVI.)

| Lamp. | Hours of test. | Life of lamp. | Candles in efficiency tests. | | Candles. | | | Discoloration. |
|---|---|---|---|---|---|---|---|---|
| | | | Spher'l. | Horiz'l. | Spher. | Horizontal. | | |
| 1 | 1,065 | 227 | 16·6 | 18·4 | 10·8 | 11·9 | After 198 hrs. | 2½ |
| 2 | 1,065 | 47 | 13·8 | 14·9 | ........... | ........... | ........................ | ½ |
| 3 | 1,065 | Survived. | 13·4 | 14·8 | 7·1 | 7·8 | After 1,006 hrs. | 2 |
| 3 | 1,065 | 107 | 11·7 | 12·7 | 3·8 | 4·2 | " 77 " | 1½ |
| 5 | 1,065 | 320 | 15·0 | 16·4 | 10·4 | 11·4 | " 289 " | 2½ |
| 6 | 1,065 | Survived. | 10·4 | 11·2 | 10·0 | 10·8 | " 1,006 " | 2 |
| 7 | 1,065 | " | 17·3 | 19·0 | 2·9 | 3·2 | " 1,006 " | 2 |
| 8 | 1,065 | 141 | 19·2 | 21·4 | 10·0 | 11·1 | " 141 " | 2½ |
| 9 | 1,065 | Survived. | 15·6 | 17·0 | 6·5 | 7·1 | " 1,006 " | 2 |
| 10 | 1,065 | 823 | 18·2 | 19·7 | 10·0 | 10·9 | " 789 " | 2 |
| 11 | 1,065 | 169 | 15·4 | 17·0 | 2·8 | 3·1 | " 148 " | 1½ |
| 12 | 1,065 | 81 | 21·3 | 23·3 | 13·9 | 15·3 | " 76 " | 2 |
| 13 | 1,065 | 256 | 15·4 | 17·0 | 6·0 | 6·6 | " 241 " | 2 |
| 14 | 1,065 | 213 | 18·3 | 20·4 | 2·6 | 2·9 | " 196 " | 1 |
| 15 | 1,065 | 193 | 8·9 | 9·4 | 5·5 | 5·9 | " 193 " | 1 |
| 16 | 1,065 | Survived. | 14·2 | 15·4 | 9·1 | 10·0 | " 1,006 " | 3 |
| 17 | 1,065 | 41 | 11·3 | 13·1 | ........... | ........... | ........................ | ½ |
| 18 | 1,065 | Survived. | 15·8 | 17·0 | 4·4 | 4·7 | " 1,006 " | 2 |
| 19 | 1,065 | 65 | 19·4 | 21·9 | 10·7 | 12·1 | " 52 " | 2 |
| 20 | 1,065 | Survived. | 18·5 | 19·9 | 9·5 | 10·2 | " 1,006 " | 2 |

## *Weston Lamps, 70 Volts.* (TABLE XVII.)

| Lamp. | Hours of test. | Life of lamp. | Candles in efficiency tests. | | Candles. | | | Discoloration. |
|---|---|---|---|---|---|---|---|---|
| | | | Spher'l. | Horiz'l. | Spher. | Horizontal. | | |
| 51 | 524 | 260 | 14·3 | 16·0 | 7·7 | 8·6 | After 249 hrs. | 2½ |
| 54 | 524 | Survived. | 14·0 | 15·2 | 13·1 | 14·4 | " 465 " | 2 |
| 55 | 524 | " | 16·7 | 18·3 | 14·8 | 16·3 | " 465 " | 2 |
| 56 | 524 | " | 14·7 | 16·4 | 13·9 | 15·7 | " 465 " | 2 |
| 58 | 524 | " | 16·3 | 17·9 | 13·3 | 14·6 | " 465 " | 2½ |
| 59 | 524 | 223 | 15·6 | 17·6 | 14·9 | 16·8 | " 176 " | 2½ |
| 61 | 524 | Survived. | 12·7 | 13·8 | 12·5 | 13·7 | " 464 " | 2 |
| 62 | 524 | " | 13·9 | 15·4 | 9·9 | 10·9 | " 464 " | 2 |
| 63 | 523 | " | 14·3 | 16·3 | 14·0 | 16·0 | " 463 " | 1½ |
| 64 | 523 | 463 | 14·8 | 16·1 | 14·0 | 15·4 | " 462 " | 2 |

# Edison Lamps.

## *Edison Lamp, No. 1, 99 Volts.*

(Reduction Factor, ·96. Resistance Cold, 260.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Mean Horizontal Candles. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 98·9 | ·690 | 68·24 | 15·90 | 15·31 | 4·45 | 18·81 | 143·3 | 1·45 | 1·45 |
| 11 | ... | ... | ... | 15·5 | 14·9 | ... | 18·3 | ... | 3·45 | 5·30 |
| 12 | ... | ... | ... | ... | ... | ... | ... | ... | 24·00 | 29·30 |
| 13 | 97·1 | ·664 | 64·48 | 12·3 | 11·8 | ... | 14·5 | 146·2 | 24·00 | 53·30 |
| 14 | 99·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 77·30 |
| 15 | 98·0 | ·663 | 64·97 | 14·1 | 13·5 | ... | 16·6 | 147·8 | 24·00 | 101·30 |
| 16 | 98·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 125·30 |
| 17 | 99·0 | ·675 | 66·83 | 13·7 | 13·2 | ... | 16·2 | 146·7 | 24·00 | 149·30 |
| 18 | 100·2 | ·679 | 68·04 | 15·1 | 14·5 | ... | 17·8 | 147·6 | 24·00 | 173·30 |
| 19 | 99·5 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 197·30 |
| 20 | 98·1 | ·655 | 64·26 | 12·4 | 11·9 | ... | 14·6 | 149·8 | 20·45 | 218·15 |
| 21 | 99·7 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 242·15 |
| 22 | 98·6 | ·662 | 65·27 | 13·1 | 12·6 | ... | 15·5 | 148·9 | 24·00 | 266·15 |
| 23 | 99·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 290·15 |
| 24 | 99·0 | ·660 | 65·34 | 12·3 | 11·8 | ... | 14·5 | 150·0 | 24·00 | 314·15 |
| *25 | 99·4 | ·665 | 66·10 | 10·4 | 10·0 | ... | 12·3 | 149·5 | 24·00 | 338·15 |
| 26 | 99·0 | ... | ... | ... | ... | ... | ... | ... | 21·00 | 359·15 |
| *27 | 98·8 | ·659 | 65·11 | 10·0 | 9·6 | ... | 11·8 | 149·9 | 24·00 | 383·15 |
| *28 | 99·0 | ·657 | 65·04 | 10·0 | 9·6 | ... | 11·8 | 150·7 | 24·00 | 407·15 |
| *29 | 99·3 | ·658 | 65·34 | 9·6 | 9·2 | ... | 11·3 | 150·9 | 24·00 | 431·15 |
| 30 | 98·7 | ·655 | 64·64 | 11·9 | 11·4 | ... | 14·0 | 150·7 | 24·00 | 455·15 |
| May | | | | | | | | | | |
| 1 | 99·1 | ·655 | 64·91 | 11·9 | 11·4 | ... | 14·0 | 151·3 | 24·00 | 479·15 |
| 2 | 98·9 | ·656 | 64·87 | 11·7 | 11·2 | ... | 13·8 | 150·8 | 24·00 | 503·15 |
| 3 | 98·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 527·15 |
| 4 | 99·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 551·15 |
| 5 | 99·2 | ·655 | 64·97 | 12·0 | 11·5 | ... | 14·1 | 151·5 | 24·00 | 575·15 |
| 6 | 98·9 | ·647 | 63·98 | 10·7 | 10·3 | ... | 12·7 | 152·9 | 23·30 | 598·45 |
| 7 | 98·8 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 622·45 |
| 8 | 98·8 | ·649 | 64·12 | 11·3 | 10·8 | ... | 13·3 | 152·2 | 24·00 | 646·45 |
| 9 | 99·0 | ·646 | 63·95 | 11·6 | 11·1 | ... | 13·3 | 153·3 | 24·00 | 670·45 |
| 10 | 98·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 694·45 |
| 11 | 98·9 | ·648 | 64·08 | 10·9 | 10·5 | ... | 12·9 | 152·6 | 24·00 | 718·45 |
| 12 | 98·8 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 742·45 |
| 13 | 99·2 | ... | ... | ... | ... | ... | ... | ... | 23·30 | 766·15 |
| 14 | 99·2 | ·646 | 64·08 | 10·5 | 10·1 | ... | 12·4 | 153·6 | 24·00 | 790·15 |
| 15 | 99·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 814·15 |
| 16 | 98·6 | ·645 | 63·59 | 11·4 | 10·9 | ... | 13·4 | 152·9 | 24·00 | 838·15 |
| 17 | 99·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 862·15 |
| 18 | 98·9 | ·642 | 63·49 | 11·3 | 10·8 | ... | 13·3 | 154·1 | 24·00 | 886·15 |
| 19 | 98·8 | ·641 | 63·33 | 9·3 | 8·9 | ... | 10·9 | 154·1 | 24·00 | 910·15 |
| 20 | 99·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 934·15 |
| 21 | 99·0 | ·639 | 63·26 | 10·5 | 10·1 | ... | 12·4 | 154·9 | 24·00 | 958·15 |
| 22 | 99·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 982·15 |
| 23 | 98·7 | ·637 | 62·87 | 9·5 | 9·1 | ... | 11·2 | 154·9 | 24·00 | 1,006·15 |
| 24 | 98·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 1,030·15 |
| *25 | 98·8 | ·639 | 63·13 | 7·3 | 7·0 | ... | 8·6 | 154·6 | 24·00 | 1,054·15 |
| 26 | ... | ... | ... | ... | ... | ... | ... | ... | 11·00 | 1,065·45 |
| 28 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

Resistance Cold, 281. Discoloration, 3.

## *Edison Lamp, No. 2, 98 Volts.*

(Reduction Factor, 1·03. Resistance Cold, 252.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles, Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 98·9 | ·703 | 69·44 | 13·95 | 14·38 | 4·83 | 17·62 | 140·7 | 1·00 | 1·00 |
| 11 | ........... | ........... | ........... | 16·0 | 16·5 | ........... | 20·3 | ........... | 3·45 | 4·45 |
| 12 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 28·45 |
| 13 | 96·3 | ·647 | 62·31 | 10·1 | 10·4 | ........... | 12·8 | 148·8 | 24·00 | 52·45 |
| 14 | 98·3 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 76·45 |
| 15 | 97·2 | ·661 | 64·25 | 12·2 | 12·6 | ........... | 15·5 | 147·1 | 24·00 | 100·45 |
| 16 | 98·8 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 124·45 |
| 17 | 98·6 | ·668 | 65·86 | 12·3 | 12·7 | ........... | 15·6 | 147·6 | 24·00 | 148·45 |
| 18 | 97·8 | ·666 | 65·13 | 11·9 | 12·3 | ........... | 15·1 | 146·8 | 24·00 | 172·45 |
| 19 | 98·6 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 196·45 |
| 20 | 97·6 | ·660 | 64·41 | 11·3 | 11·6 | ........... | 14·3 | 147·9 | 20·45 | 217·30 |
| 21 | 98·8 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 241·30 |
| 22 | 97·7 | ·660 | 64·48 | 11·1 | 11·4 | ........... | 14·0 | 148·0 | 24·00 | 265·30 |
| 23 | 98·4 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 289·30 |
| 24 | 98·2 | ·654 | 64·22 | 10·7 | 11·0 | ........... | 13·5 | 150·2 | 24·00 | 313·30 |
| *25 | 98·4 | ·664 | 65·34 | 10·0 | 10·3 | ........... | 12·7 | 148·2 | 24·00 | 337·30 |
| 26 | 98·1 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 21·00 | 358·30 |
| *27 | 97·9 | ·656 | 64·22 | 9·2 | 9·5 | ........... | 11·7 | 149·2 | 24·00 | 382·30 |
| *28 | 98·0 | ·657 | 64·38 | 7·9 | 8·1 | ........... | 10·0 | 149·2 | 24·00 | 406·30 |
| *29 | 98·2 | ·658 | 64·61 | 8·9 | 9·2 | ........... | 11·3 | 149·2 | 24·00 | 430·30 |
| 30 | 97·8 | ·653 | 63·86 | 10·6 | 10·9 | ........... | 13·4 | 149·8 | 24·00 | 454·30 |
| May. | | | | | | | | | | |
| 1 | 98·1 | ·656 | 64·35 | 10·7 | 11·0 | ........... | 13·5 | 149·5 | 24·00 | 478·30 |
| 2 | 97·8 | ·656 | 64·15 | 11·0 | 11·3 | ........... | 13·9 | 149·1 | 24·00 | 502·30 |
| 3 | 98·0 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 526·30 |
| 4 | 97·9 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 550·30 |
| 5 | 98·0 | ·657 | 64·38 | 11·3 | 11·6 | ........... | 14·3 | 149·2 | 24·00 | 574·30 |
| 6 | 97·8 | ·651 | 63·66 | 10·1 | 10·4 | ........... | 12·8 | 150·2 | 23·30 | 598·00 |
| 7 | 97·8 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 622·00 |
| 8 | 97·9 | ·655 | 64·12 | 11·3 | 11·6 | ........... | 14·3 | 149·5 | 24·00 | 646·00 |
| 9 | 98·0 | ·657 | 64·38 | 11·4 | 11·7 | ........... | 14·4 | 149·2 | 24·00 | 670·00 |
| 10 | 97·7 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 694·00 |
| 11 | 97·9 | ·653 | 63·92 | 10·6 | 10·9 | ........... | 13·4 | 149·9 | 24·00 | 718·00 |
| 12 | 98·0 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 742·00 |
| 13 | 98·5 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 23·00 | 765·00 |
| 14 | 98·0 | ·655 | 64·19 | 10·0 | 10·3 | ........... | 12·7 | 149·6 | 24·00 | 789·30 |
| 15 | 98·0 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 813·30 |
| 16 | 97·7 | ·650 | 63·50 | 10·8 | 11·1 | ........... | 13·7 | 150·3 | 24·00 | 837·30 |
| 17 | 98·0 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 861·30 |
| 18 | 97·7 | ·649 | 63·40 | 11·0 | 11·3 | ........... | 13·9 | 150·5 | 24·00 | 885·30 |
| 19 | 97·7 | ·648 | 63·31 | 8·7 | 9·0 | ........... | 11·1 | 150·8 | 24·00 | 909·30 |
| 20 | 97·9 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 933·30 |
| 21 | 98·0 | ·648 | 63·50 | 10·3 | 10·6 | ........... | 13·0 | 151·2 | 24·00 | 957·30 |
| 22 | 97·8 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 981·30 |
| 23 | 97·6 | ·646 | 63·04 | 9·3 | 9·6 | ........... | 11·8 | 151·1 | 24·00 | 1,005·30 |
| 24 | 97·9 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 1,029·30 |
| *25 | 97·7 | ·646 | 63·11 | 7·3 | 7·5 | ........... | 9·2 | 151·2 | 24·00 | 1,053·30 |
| 26 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 11·30 | 1,065·00 |
| 28 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... |

Resistance Cold, 267. Discoloration, 2.

## *Edison Lamp, No. 3, 95 Volts.*

(Reduction Factor, 0·91. Resistance Cold, 241.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 95·8 | ·711 | 68·12 | 16·32 | 14·87 | 4·58 | 18·03 | 134·7 | 0·30 | 0·30 |
| 11 | ... | ... | ... | 13·3 | 12·1 | ... | 14·6 | ... | 3·45 | 4·15 |
| 12 | ... | ... | ... | ... | ... | ... | ... | ... | 24·00 | 28·15 |
| 13 | 93·5 | ·650 | 60·77 | 10·4 | 9·5 | ... | 11·5 | 143·8 | 24·00 | 52·15 |
| 14 | 95·4 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 76·15 |
| 15 | 94·2 | ·664 | 62·55 | 12·1 | 11·0 | ... | 13·3 | 141·9 | 24·00 | 100·15 |
| 16 | 97·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 124·15 |
| 17 | 95·7 | ·675 | 64·60 | 12·1 | 11·0 | ... | 13·3 | 141·5 | 24·00 | 148·15 |
| 18 | 95·2 | ·668 | 63·59 | 12·0 | 10·9 | ... | 13·2 | 142·5 | 24·00 | 172·15 |
| 19 | 95·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 196·15 |
| 20 | 94·5 | ·667 | 63·03 | 12·2 | 11·1 | ... | 13·4 | 141·7 | 20·45 | 217·00 |
| 21 | 96·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 241·00 |
| 22 | 95·2 | ·661 | 62·92 | 11·6 | 10·6 | ... | 12·8 | 144·0 | 24·00 | 265·00 |
| 23 | 95·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 289·00 |
| 24 | 95·1 | ·669 | 63·62 | 11·4 | 10·4 | ... | 12·6 | 142·2 | 24·00 | 313·00 |
| *25 | 95·2 | ·661 | 62·92 | 9·8 | 8·9 | ... | 10·8 | 144·0 | 24·00 | 337·00 |
| 26 | 95·3 | ... | ... | ... | ... | ... | ... | ... | 21·00 | 358·00 |
| *27 | 95·0 | ·658 | 62·51 | 9·4 | 8·6 | ... | 10·4 | 144·4 | 24·00 | 382·00 |
| *28 | 94·6 | ·674 | 63·76 | 10·4 | 9·5 | ... | 11·5 | 140·4 | 24·00 | 406·00 |
| *29 | 94·9 | ·675 | 64·05 | 10·5 | 9·6 | ... | 11·6 | 140·6 | 24·00 | 430·00 |
| 30 | 94·4 | ·671 | 63·34 | 12·4 | 11·3 | ... | 13·7 | 140·7 | 24·00 | 454·00 |
| May. | | | | | | | | | | |
| 1 | 94·7 | ·671 | 63·54 | 12·9 | 11·7 | ... | 14·2 | 141·1 | 24·00 | 478·00 |
| 2 | 94·9 | ·679 | 64·43 | 12·9 | 11·7 | ... | 14·2 | 139·8 | 24·00 | 502·00 |
| 3 | 94·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 526·00 |
| 4 | 95·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 550·00 |
| 5 | 95·0 | ·674 | 64·03 | 13·2 | 12·0 | ... | 14·5 | 140·9 | 24·00 | 574·00 |
| 6 | 94·8 | ·673 | 63·80 | 11·7 | 10·6 | ... | 12·8 | 140·9 | 23·30 | 597·00 |
| 7 | 94·8 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 621·30 |
| 8 | 94·8 | ·669 | 63·42 | 13·2 | 12·0 | ... | 14·5 | 141·7 | 24·00 | 645·30 |
| 9 | 95·0 | ·670 | 63·63 | 12·5 | 11·4 | ... | 13·8 | 141·8 | 24·00 | 669·30 |
| 10 | 94·8 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 693·30 |
| 11 | 95·0 | ·670 | 63·64 | 12·0 | 10·9 | ... | 13·2 | 141·8 | 24·00 | 717·30 |
| 12 | 94·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 741·30 |
| 13 | 95·0 | ... | ... | ... | ... | ... | ... | ... | 23·30 | 765·00 |
| 14 | 95·0 | ·670 | 63·64 | 11·3 | 10·3 | ... | 12·5 | 141·8 | 24·00 | 789·00 |
| 15 | 95·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 813·00 |
| 16 | 94·8 | ·667 | 63·23 | 12·0 | 10·9 | ... | 13·2 | 142·1 | 24·00 | 837·00 |
| 17 | 95·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 861·00 |
| 18 | 95·0 | ·665 | 63·17 | 12·6 | 11·5 | ... | 13·9 | 142·9 | 24·00 | 885·00 |
| 19 | 94·8 | ·664 | 62·94 | 10·5 | 9·6 | ... | 11·6 | 142·8 | 24·00 | 909·00 |
| 20 | 94·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 933·00 |
| 21 | 94·9 | ·664 | 63·01 | 11·6 | 10·6 | ... | 12·8 | 142·9 | 24·00 | 957·00 |
| 22 | 95·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 981·00 |
| 23 | 94·8 | ·661 | 62·66 | 10·5 | 9·6 | ... | 11·6 | 143·4 | 24·00 | 1,005·00 |
| 24 | 94·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 1,029·00 |
| *25 | 94·8 | ·662 | 62·75 | 8·3 | 7·6 | ... | 9·2 | 143·2 | 24·00 | 1,053·00 |
| 26 | ... | ... | ... | ... | ... | ... | ... | ... | 11·30 | 1,064·30 |
| 28 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

Resistance Cold, 257. Discoloration, 2.

## *Edison Lamp, No. 4, 95 Volts.*

(Reduction Factor, 0·93. Resistance Cold, 244.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 95·8 | ·718 | 68·79 | 16·90 | 15·72 | 4·37 | 19·44 | 133·4 | 0·30 | 0·30 |
| 11 | ... | ... | ... | 17·4 | 16·2 | ... | 20·1 | ... | 3·45 | 4·15 |
| 12 | ... | ... | ... | ... | ... | ... | ... | ... | 24·00 | 28·15 |
| 13 | 93·3 | ·676 | 63·07 | 13·6 | 12·7 | ... | 15·7 | 138·0 | 24·00 | 52·15 |
| 14 | 95·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 76·15 |
| 15 | 93·7 | ·682 | 63·91 | 15·2 | 14·1 | ... | 17·5 | 137·4 | 24·00 | 100·15 |
| 16 | 97·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 124·15 |
| 17 | 95·5 | ·692 | 66·09 | 14·5 | 13·5 | ... | 16·7 | 138·0 | 24·00 | 148·15 |
| 18 | 95·3 | ·690 | 65 96 | 14·5 | 13·5 | ... | 16·7 | 138·6 | 24·00 | 172·15 |
| 19 | 95·8 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 196·15 |
| 20 | 96·0 | ·693 | 66·53 | 15·6 | 14·5 | ... | 18·0 | 138·5 | 20·45 | 217·00 |
| 21 | 96·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 241·00 |
| 22 | 95·1 | ·678 | 64·47 | 13·7 | 12·7 | ... | 15·7 | 140·3 | 24·00 | 265·00 |
| 23 | 95·3 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 289·00 |
| 24 | 95·2 | ·677 | 64·45 | 12·8 | 11·9 | ... | 14·8 | 140·6 | 24·00 | 313·00 |
| *25 | 95·2 | ·673 | 64·07 | 11·7 | 10·9 | ... | 13·5 | 141·5 | 24·00 | 337·00 |
| 26 | 95·2 | ... | ... | ... | ... | ... | ... | ... | 21·00 | 358·00 |
| *27 | 94·8 | ·671 | 63·61 | 11·2 | 10·4 | ... | 12·9 | 141·3 | 24·00 | 382·00 |
| *28 | 95·0 | ·670 | 63·65 | 10·1 | 9·4 | ... | 11·7 | 141 8 | 24·00 | 406·00 |
| *.9 | 95·2 | ·672 | 63·97 | 10·2 | 9·5 | ... | 11·8 | 141·7 | 24·00 | 430·00 |
| 30 | 95·3 | ·674 | 64·23 | 13·1 | 12·2 | ... | 15·1 | 141·4 | 24·00 | 454·00 |
| May. | | | | | | | | | | |
| 1 | 95·2 | ·673 | 64·07 | 12·6 | 11·7 | ... | 14·5 | 141·5 | 24 00 | 478·00 |
| 2 | 95·0 | ·670 | 63 64 | 12·4 | 11·5 | ... | 14·3 | 141·8 | 24·00 | 502·00 |
| 3 | 95·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 526·00 |
| 4 | 95·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 550·00 |
| 5 | 95·1 | ·668 | 63·52 | 13·2 | 12·3 | ... | 15·3 | 142·4 | 24·00 | 574·00 |
| 6 | 95·2 | ·668 | 63·59 | 11·7 | 10·9 | ... | 13·5 | 142·5 | 23·30 | 597·30 |
| 7 | 94·8 | ... | ... | ... | ... | ... | 14·4 | ... | 24·00 | 621·30 |
| 8 | 95·0 | ·665 | 63·17 | 12·5 | 11·6 | ... | 14·4 | 142·9 | 24·00 | 645·30 |
| 9 | 95·2 | ·665 | 63·31 | 12·5 | 11·6 | ... | ... | 143·2 | 24·00 | 669·30 |
| 10 | 94·8 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 693·30 |
| 11 | 95·0 | ·664 | 63·08 | 11·7 | 10·9 | ... | 13·5 | 143·1 | 24·00 | 717·30 |
| 12 | 94·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 741·30 |
| 13 | 95·5 | ... | ... | ... | ... | ... | ... | ... | 23·30 | 765·00 |
| 14 | 95·1 | ·659 | 62·67 | 10·7 | 10·0 | ... | 12·4 | 144·3 | 24·00 | 789·00 |
| 15 | 95·3 | ... | ... | ... | ... | ... | ... | ... | 24 00 | 813·00 |
| 16 | 94·9 | ·660 | 62·63 | 11·6 | 10·8 | ... | 13·4 | 143·8 | 24·00 | 837·00 |
| 17 | 95·3 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 861·00 |
| 18 | 95·2 | ·659 | 62·73 | 11·3 | 10·5 | ... | 13·0 | 144·5 | 24·00 | 885·00 |
| 19 | 94·8 | ·658 | 62·37 | 9·9 | 9·2 | ... | 11·4 | 144·1 | 24·00 | 909·00 |
| 20 | 95·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 933·00 |
| 21 | 95·2 | ·658 | 62·64 | 11·2 | 10·4 | ... | 12·9 | 144·7 | 24·00 | 957·00 |
| 22 | 95·5 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 981·00 |
| 23 | 94·8 | ·653 | 61·90 | 10·2 | 9·5 | ... | 11·8 | 145·2 | 24·00 | 1,005·00 |
| 24 | 94·8 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 1,029·00 |
| *25 | 95·0 | ·656 | 62·31 | 8 1 | 7·5 | ... | 9·3 | 144·8 | 24·00 | 1,053·00 |
| 26 | ... | ... | ... | ... | ... | ... | ... | ... | 11·30 | 1,064·30 |
| 28 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

Resistance Cold, 264. Discoloration, 2½.

## *Edison Lamp, No. 5, 97 Volts.*

(Reduction Factor, 0·95. Resistance Cold, 244.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts, per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 97·8 | ·718 | 70·21 | 17·32 | 16·41 | 4·27 | 20·23 | 136·2 | 0·30 | 0·30 |
| 11 | ...... | ...... | ...... | 18·4 | 17·5 | ...... | 21·7 | ...... | 3·45 | 4·15 |
| 12 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 28·15 |
| 13 | 95·2 | ·685 | 65·22 | 14·4 | 13·7 | ...... | 17·0 | 139·0 | 24·00 | 52·15 |
| 14 | 97·0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 76·15 |
| 15 | 95·6 | ·682 | 65·20 | 15·9 | 15·1 | ...... | 18·7 | 140·2 | 24·00 | 100·15 |
| 16 | 98·7 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 124·15 |
| 17 | 97·2 | ·699 | 67·94 | 16·9 | 16·0 | ...... | 19·8 | 139·1 | 24·00 | 148·15 |
| 18 | 96·5 | ·691 | 66·69 | 15·3 | 14·5 | ...... | 18·0 | 139·7 | 24·00 | 172·15 |
| 19 | 97·3 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 196·15 |
| 20 | 98·5 | ·691 | 68·07 | 15·1 | 14·3 | ...... | 17·7 | 142·5 | 20·45 | 217·00 |
| 21 | 98·0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 241·00 |
| 22 | 96·5 | ·687 | 66·30 | 15·0 | 14·3 | ...... | 17·7 | 140·5 | 24·00 | 265·00 |
| 23 | 97·7 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 289·00 |
| 24 | 97·2 | ·669 | 65·03 | 12·3 | 11·7 | ...... | 14·5 | 145·3 | 24·00 | 313·00 |
| *25 | 97·4 | ·670 | 65·25 | 11·3 | 10·7 | ...... | 13·3 | 145·4 | 24·00 | 337·00 |
| 26 | 97·0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 21·00 | 358·00 |
| *27 | 96·6 | ·684 | 66·07 | 11·9 | 11·3 | ...... | 14·0 | 141·2 | 24·00 | 382·00 |
| *28 | 97·2 | ·664 | 64·54 | 10·1 | 9·6 | ...... | 11·9 | 146·4 | 24·00 | 406·00 |
| *29 | 97·3 | ·670 | 65·19 | 10·2 | 9·7 | ...... | 12·0 | 145·2 | 24·00 | 430·00 |
| 30 | 97·1 | ·675 | 65·54 | 13·3 | 12·6 | ...... | 15·6 | 143·9 | 24·00 | 454·00 |
| May. | | | | | | | | | | |
| 1 | 97·4 | ·661 | 64·38 | 11·5 | 10·9 | ...... | 13·5 | 147·4 | 24·00 | 478·00 |
| 2 | 97·2 | ·664 | 64·54 | 11·4 | 10·8 | ...... | 13·4 | 146·4 | 24·00 | 502·00 |
| 3 | 97·2 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 526·00 |
| 4 | 97·1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 550·00 |
| 5 | 97·3 | ·662 | 64·41 | 12·6 | 12·0 | ...... | 14·9 | 147·0 | 24·00 | 574·00 |
| 6 | 97·2 | ·662 | 64·34 | 11·5 | 10·9 | ...... | 13·5 | 146·8 | 23·30 | 597·30 |
| 7 | 97·0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 621·30 |
| 8 | 97·3 | ·660 | 64·21 | 11·9 | 11·3 | ...... | 14·0 | 147·4 | 24·00 | 645·30 |
| 9 | 97·5 | ·658 | 64·16 | 11·4 | 10·8 | ...... | 13·4 | 148·2 | 24·00 | 669·30 |
| 10 | 97·2 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 693·30 |
| 11 | 97·1 | ·658 | 63·89 | 11·1 | 10·5 | ...... | 13·0 | 147·6 | 24·00 | 717·30 |
| 12 | 97·4 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 741·30 |
| 13 | 97·1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 23·30 | 765·00 |
| 14 | 96·9 | ·655 | 63·46 | 10·0 | 9·5 | ...... | 11·8 | 147·9 | 24·00 | 789·00 |
| 15 | 97·0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 813·00 |
| 16 | 96·7 | ·655 | 63·33 | 11·2 | 10·6 | ...... | 13·1 | 147·6 | 24·00 | 837·00 |
| 17 | 96·8 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 861·00 |
| 18 | 96·3 | ·670 | 64·52 | 13·5 | 12·8 | ...... | 15·9 | 143·7 | 24·00 | 885·00 |
| 19 | 96·9 | ·665 | 64·43 | 10·6 | 10·1 | ...... | 12·5 | 145·7 | 24·00 | 909·00 |
| 20 | 97·0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 933·00 |
| 21 | 97·4 | ·658 | 64·09 | 11·5 | 10·9 | ...... | 13·5 | 148·0 | 24·00 | 957·00 |
| 22 | 97·5 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 981·00 |
| 23 | 96·7 | ·665 | 64·30 | 10·8 | 10·3 | ...... | 12·8 | 145·5 | 24·00 | 1,005·00 |
| 24 | 97·0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 1,029·00 |
| *25 | 97·1 | ·658 | 63·89 | 8·1 | 7·7 | ...... | 9·5 | 147·6 | 24·00 | 1,053·00 |
| 26 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 11·30 | 1,064·30 |
| 28 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |

Resistance Cold, 260. Discoloration, 2½.

## *Edison Lamp, No. 6, 99 Volts.*

(Reduction Factor, 0·91. Resistance Cold, 264.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Candles. | Candles, Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 99·9 | ·692 | 69·13 | 16·07 | 14·67 | 4·71 | 17·98 | 144·4 | 0·30 | 0·30 |
| 11 | ... | ... | ... | 18·6 | 16·9 | ... | 20·8 | ... | 3·45 | 4·15 |
| 12 | ... | ... | ... | ... | ... | ... | ... | ... | 24·00 | 28·15 |
| 13 | 97·8 | ·669 | 65·42 | 14·9 | 13·5 | ... | 16·6 | 146·2 | 24·00 | 52·15 |
| 14 | 99·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 76·15 |
| 15 | 97·7 | ·659 | 64·38 | 15·8 | 14·4 | ... | 17·7 | 148·3 | 24·00 | 100·15 |
| 16 | 100·8 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 124·15 |
| 17 | 99·6 | ·674 | 67·13 | 16·0 | 14·6 | ... | 18·0 | 147·8 | 24·00 | 148·15 |
| 18 | 99·1 | ·670 | 66·40 | 16·2 | 14·7 | ... | 18·1 | 147·9 | 24·00 | 172·15 |
| 19 | 99·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 196·15 |
| 20 | 99·8 | ·677 | 67·56 | 15·4 | 14·0 | ... | 17·2 | 147·4 | 20·45 | 217·00 |
| 21 | 99·6 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 241·00 |
| 22 | 98·9 | ·664 | 65·66 | 15·4 | 14·0 | ... | 17·2 | 148·9 | 24·00 | 265·00 |
| 23 | 99·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 289·00 |
| 24 | 99·1 | ·661 | 65·50 | 13·1 | 11·9 | ... | 14·6 | 149·9 | 24·00 | 313·00 |
| *25 | 99·2 | ·660 | 65·47 | 13·0 | 11·8 | ... | 15·5 | 150·3 | 24·00 | 337·00 |
| 26 | 99·0 | ... | ... | ... | ... | ... | ... | ... | 21·00 | 358·00 |
| *27 | 99·1 | ·660 | 65·40 | 12·0 | 10·9 | ... | 13·4 | 150·2 | 24·00 | 382·00 |
| *28 | 99·0 | ·659 | 65·24 | 11·1 | 10·1 | ... | 12·4 | 150·2 | 24·00 | 406·00 |
| *29 | 99·0 | ·659 | 65·24 | 11·2 | 10·2 | ... | 12·5 | 150·2 | 24·00 | 430·00 |
| 30 | 99·1 | ·658 | 65·20 | 13·8 | 12·6 | ... | 15·5 | 150·6 | 24·00 | 454·00 |
| May. | | | | | | | | | | |
| 1 | 99·2 | ·658 | 65·27 | 14·0 | 12·7 | ... | 15·6 | 150·8 | 24·00 | 478·00 |
| 2 | 98·9 | ·655 | 64·78 | 13·2 | 12·0 | ... | 14·8 | 151·0 | 24·00 | 502·00 |
| 3 | 99·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 526·00 |
| 4 | 98·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 550·00 |
| 5 | 98·9 | ·652 | 64·48 | 14·0 | 12·7 | ... | 15·6 | 151·7 | 24·00 | 574·00 |
| 6 | 99·2 | ·650 | 64·47 | 12·8 | 11·6 | ... | 14·3 | 152·6 | 23·30 | 597·30 |
| 7 | 98·8 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 621·30 |
| 8 | 98·9 | ·650 | 64·28 | 13·6 | 12·4 | ... | 15·3 | 152·2 | 24·00 | 645·30 |
| 9 | 99·1 | ·650 | 64·41 | 13·3 | 12·1 | ... | 14·9 | 152·5 | 24·00 | 669·30 |
| 10 | 98·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 693·30 |
| 11 | 98·9 | ·650 | 64·28 | 12·7 | 11·6 | ... | 14·3 | 152·2 | 24·00 | 717·30 |
| 12 | 99·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 741·30 |
| 13 | 99·1 | ... | ... | ... | ... | ... | ... | ... | 23·30 | 765·00 |
| 14 | 99·0 | ·647 | 64·05 | 11·6 | 10·6 | ... | 13·0 | 153·0 | 24·00 | 789·00 |
| 15 | 99·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 813·00 |
| 16 | 98·8 | ·645 | 63·72 | 12·7 | 11·6 | ... | 14·3 | 153·2 | 24·00 | 837·00 |
| 17 | 98·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 861·00 |
| 18 | 98·9 | ·646 | 63·89 | 13·4 | 12·2 | ... | 15·0 | 153·1 | 24·00 | 885·00 |
| 19 | 99·0 | ·645 | 63·85 | 11·4 | 10·4 | ... | 12·8 | 153·5 | 24·00 | 909·00 |
| 20 | 98·1 | ... | ... | ... | ... | ... | ... | ... | 24.00 | 933·00 |
| 21 | 98·8 | ·642 | 63·43 | 12·6 | 11·5 | ... | 14·1 | 153·9 | 24·00 | 957·00 |
| 22 | 99·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 981·00 |
| 23 | 98·8 | ·641 | 63·33 | 11·1 | 10·1 | ... | 12·4 | 154·1 | 24·00 | 1,005·00 |
| 24 | 99·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 1,029·00 |
| *25 | 99·1 | ·642 | 63·62 | 8·5 | 7·7 | ... | 9·5 | 151·4 | 24·00 | 1,053·00 |
| 26 | ... | ... | ... | ... | ... | ... | ... | ... | 11·30 | 1,064·30 |
| 28 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

Resistance Cold, 279. Discoloration, 2½.

## *Edison Lamp, No. 7, 95 Volts.*

(Reduction Factor, 0·88. Resistance Cold, 235.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 95·8 | ·736 | 70·31 | 16·50 | 14·57 | 4·82 | 18·43 | 130·2 | 0·45 | 0·45 |
| 11 | ... | ... | ... | 16·8 | 14·8 | ... | 18·6 | ... | 3·45 | 4·30 |
| 12 | ... | ... | ... | ... | ... | ... | ... | ... | 24·00 | 28·30 |
| 13 | 93·8 | ·699 | 65·57 | 12·9 | 11·4 | ... | 14·4 | 134·2 | 24·00 | 52·30 |
| 14 | 95·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 76·30 |
| 15 | 94·2 | ·692 | 65·19 | 14·4 | 12·7 | ... | 16·0 | 136·1 | 24·00 | 100·30 |
| 16 | 96·7 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 124·30 |
| 17 | 95·8 | ·709 | 67·92 | 14·2 | 12·5 | ... | 15·8 | 135·1 | 24·00 | 148·30 |
| 18 | 95·6 | ·703 | 67·21 | 15·1 | 13·3 | ... | 16·8 | 136·0 | 24·00 | 172·30 |
| 19 | 95·4 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 196·30 |
| 20 | 94·5 | ·699 | 66·05 | 13·7 | 12·1 | ... | 15·2 | 135·2 | 20·45 | 217·15 |
| 21 | 95·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 241·15 |
| 22 | 95·0 | ·695 | 66·03 | 13·7 | 12·1 | ... | 15·2 | 136·7 | 24·00 | 265·15 |
| 23 | 95·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 289·15 |
| 24 | 94·9 | ·698 | 66·24 | 11·6 | 10·2 | ... | 12·9 | 136·0 | 24·00 | 313·15 |
| *25 | 95·2 | ·700 | 66·64 | 12·2 | 10·7 | ... | 13·5 | 136·0 | 24·00 | 337·15 |
| 26 | 95·1 | ... | ... | ... | ... | ... | ... | ... | 21·00 | 358·15 |
| *27 | 95·1 | ·695 | 66·09 | 11·4 | 10·0 | ... | 12·6 | 136·8 | 24·00 | 382·15 |
| *28 | 95·0 | ·685 | 65·07 | 10·5 | 9·2 | ... | 11·6 | 138·7 | 24·00 | 406·15 |
| *29 | 95·1 | ·691 | 65·71 | 10·2 | 9·0 | ... | 11·3 | 137·6 | 24·00 | 430·15 |
| 30 | 95·2 | ·693 | 65·97 | 13·0 | 11·4 | ... | 14·4 | 137·4 | 24·00 | 454·15 |
| May. | | | | | | | | | | |
| 1 | 95·0 | ·691 | 65·64 | 12·1 | 10·6 | ... | 13·4 | 137·5 | 24·00 | 478·15 |
| 2 | 95·0 | ·690 | 65·55 | 12·9 | 11·4 | ... | 14·4 | 137·7 | 24·00 | 502·15 |
| 3 | 94·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 526·15 |
| 4 | 95·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 550·15 |
| 5 | 94·9 | ·688 | 65·29 | 13·4 | 11·8 | ... | 14·9 | 137·9 | 24·00 | 574·15 |
| 6 | 95·1 | ·688 | 65·42 | 12·1 | 10·6 | ... | 13·4 | 138·2 | 23·30 | 597·45 |
| 7 | 94·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 621·45 |
| 8 | 95·1 | ·687 | 65·33 | 12·8 | 11·3 | ... | 14·2 | 138·4 | 24·00 | 645·45 |
| 9 | 95·1 | ·686 | 65·24 | 12·1 | 10·6 | ... | 13·4 | 138·6 | 24·00 | 669·45 |
| 10 | 94·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 693·45 |
| 11 | 95·0 | ·686 | 65·16 | 12·0 | 10·6 | ... | 13·4 | 138·5 | 24·00 | 717·45 |
| 12 | 94·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 741·45 |
| 13 | 95·1 | ... | ... | ... | ... | ... | ... | ... | 23·30 | 765·15 |
| 14 | 95·1 | ·684 | 65·04 | 11·1 | 9·8 | ... | 12·3 | 139·0 | 24·00 | 789·15 |
| 15 | 95·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 813·15 |
| 16 | 94·8 | ·683 | 64·74 | 11·7 | 10·3 | ... | 13·0 | 138·8 | 24·00 | 837·15 |
| 17 | 95·3 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 861·15 |
| 18 | 94·9 | ·681 | 64·62 | 12·2 | 10·7 | ... | 13·5 | 139·4 | 24·00 | 885·15 |
| 19 | 95·0 | ·682 | 64·78 | 10·5 | 9·2 | ... | 11·6 | 139·3 | 24·00 | 909·15 |
| 20 | 94·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 933·15 |
| 21 | 95·0 | ·678 | 64·41 | 11·5 | 10·1 | ... | 12·7 | 140·1 | 24·00 | 957·15 |
| 22 | 94·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 981·15 |
| 23 | 94·9 | ·676 | 64·15 | 10·4 | 9·2 | ... | 11·6 | 140·3 | 24·00 | 1,005·15 |
| 24 | 95·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 1,029·15 |
| *25 | 95·1 | ·678 | 64·47 | 8·2 | 7·2 | ... | 9·1 | 140·3 | 24·00 | 1,053·15 |
| 26 | ... | ... | ... | ... | ... | ... | ... | ... | 11·30 | 1,064·45 |
| 28 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

Resistance Cold, 249. Discoloration, 2½.

## *Edison Lamp, No. 8, 97 Volts.*

(Reduction Factor, 0·84. Resistance Cold, 239.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 97·9 | ·729 | 71·37 | 19·97 | 16·81 | 4·24 | 20·32 | 134·3 | 0·45 | 0·45 |
| 11 | ... | ... | ... | 20·0 | 16·8 | ... | 20·3 | ... | 3·45 | 4·30 |
| 12 | ... | ... | ... | ... | ... | ... | ... | ... | 24·00 | 28·30 |
| 13 | 95·9 | ·696 | 66·75 | 17·0 | 14·3 | ... | 17·3 | 137·8 | 24·00 | 52·30 |
| 14 | 96·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 76·30 |
| 15 | 95·9 | ·699 | 67·03 | 18·3 | 15·4 | ... | 18·6 | 137·2 | 24·00 | 100·30 |
| 16 | 98·4 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 124·30 |
| 17 | 97·2 | ·712 | 69·20 | 18·7 | 15·7 | ... | 19·0 | 136·5 | 24·00 | 148·30 |
| 18 | 97·2 | ·703 | 68·33 | 17·7 | 14·9 | ... | 18·0 | 138·3 | 24·00 | 172·30 |
| 19 | 97·5 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 196·30 |
| 20 | 96·5 | ·699 | 67·45 | 17·1 | 14·4 | ... | 17·4 | 138·1 | 20·45 | 217·15 |
| 21 | 97·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 241·15 |
| 22 | 96·8 | ·697 | 67·47 | 16·2 | 13·6 | ... | 16·5 | 138·9 | 24·00 | 265·15 |
| 23 | 97·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 289·15 |
| 24 | 96·8 | ·694 | 67·18 | 14·1 | 11·8 | ... | 14·3 | 139·5 | 24·00 | 313·15 |
| *25 | 97·0 | ·695 | 67·41 | 14·1 | 11·8 | ... | 14·3 | 139·6 | 24·00 | 337·15 |
| 26 | 97·1 | ... | ... | ... | ... | ... | ... | ... | 21·00 | 358·15 |
| *27 | 97·1 | ·693 | 67·29 | 13·2 | 11·1 | ... | 13·4 | 140·1 | 24·00 | 382·15 |
| *28 | 97·1 | ·692 | 67·19 | 12·1 | 10·2 | ... | 12·3 | 140·3 | 24·00 | 406·15 |
| *29 | 97·2 | ·691 | 67·16 | 11·9 | 10·0 | ... | 12·1 | 140·7 | 24·00 | 430·15 |
| 30 | 97·0 | ·692 | 67·12 | 15·1 | 12·7 | ... | 15·4 | 140·2 | 24·00 | 454·15 |
| May. | | | | | | | | | | |
| 1 | 97·1 | ·690 | 67·00 | 14·3 | 12·0 | ... | 14·5 | 140·7 | 24·00 | 478·15 |
| 2 | 96·8 | ·689 | 66·69 | 14·9 | 12·5 | ... | 15·1 | 140·5 | 24·00 | 502·15 |
| 3 | 97·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 526·15 |
| 4 | 97·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 550·15 |
| 5 | 97·0 | ·686 | 66·54 | 15·1 | 12·7 | ... | 15·4 | 141·4 | 24·00 | 574·15 |
| 6 | 97·0 | ·684 | 66·34 | 13·5 | 11·3 | ... | 13·7 | 141·8 | 23·30 | 597·45 |
| 7 | 96·8 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 621·45 |
| 8 | 97·0 | ·682 | 66·15 | 14·6 | 12·3 | ... | 14·9 | 142·2 | 24·00 | 645·45 |
| 9 | 97·1 | ·682 | 66·22 | 14·3 | 12·0 | ... | 14·5 | 142·4 | 24·00 | 669·45 |
| 10 | 96·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 693·45 |
| 11 | 96·9 | ·682 | 66·08 | 13·5 | 11·3 | ... | 13·7 | 142·1 | 24·00 | 717·45 |
| 12 | 97·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 741·45 |
| 13 | 97·2 | ... | ... | ... | ... | ... | ... | ... | 23·30 | 765·15 |
| 14 | 97·1 | ·678 | 65·83 | 12·4 | 10·4 | ... | 12·6 | 143·2 | 24·00 | 789·15 |
| 15 | 97·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 813·15 |
| 16 | 97·0 | ·680 | 65·96 | 13·9 | 11·7 | ... | 14·2 | 142·6 | 24·00 | 837·15 |
| 17 | 97·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 861·15 |
| 18 | 97·2 | ·678 | 65·90 | 13·7 | 11·5 | ... | 13·9 | 143·4 | 24·00 | 885·15 |
| 19 | 97·0 | ·677 | 65·66 | 11·7 | 9·8 | ... | 11·9 | 143·3 | 24·00 | 909·15 |
| 20 | 97·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 933·15 |
| 21 | 97·0 | ·674 | 65·37 | 12·8 | 10·8 | ... | 13·1 | 143·9 | 24·00 | 957·15 |
| 22 | 97·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 981·15 |
| 23 | 96·8 | ·671 | 64·95 | 11·8 | 9·9 | ... | 12·0 | 144·3 | 24·00 | 1,005·15 |
| 24 | 96·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 1,029·15 |
| *25 | 97·0 | ·674 | 65·37 | 9·4 | 7·9 | ... | 9·6 | 143·9 | 24·00 | 1,053·15 |
| 26 | ... | ... | ... | ... | ... | ... | ... | ... | 11·30 | 1,064·45 |
| 28 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

Resistance Cold, 259. Discoloration, 3.

## *Edison Lamp, No. 9, 95 Volts.*

(Reduction Factor, 1·00. Resistance Cold, 240.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 95·8 | ·718 | 68·79 | 15·1 | 15·11 | 4·55 | 18·51 | 133·4 | 0·30 | 0·30 |
| 11 | .......... | .......... | .......... | 15·5 | 15·5 | .......... | 19·1 | .......... | 3. 45 | 4·15 |
| 12 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 28·15 |
| 13 | 94·2 | ·686 | 64·62 | 13·2 | 13·2 | .......... | 16·2 | 137·3 | 24·00 | 52·15 |
| 14 | 95·0 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 76·15 |
| 15 | 94·3 | ·691 | 65·16 | 1·43 | 14·3 | .......... | 17·6 | 136·5 | 24·00 | 100·15 |
| 16 | 96·7 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 124·15 |
| 17 | 94·7 | ·696 | 65·91 | 13·8 | 13·8 | .......... | 17·0 | 136·1 | 24·00 | 148·15 |
| 18 | 94·6 | ·692 | 65·46 | 14·3 | 14·3 | .......... | 17·6 | 136·7 | 24·00 | 172·15 |
| 19 | 95·9 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 196·15 |
| 20 | 94·0 | ·686 | 64·48 | 12·1 | 12·1 | .......... | 14·9 | 137·0 | 20·45 | 217·00 |
| 21 | 95 3 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 241·00 |
| 22 | 94·8 | ·688 | 65·22 | 12·9 | 12·9 | .......... | 15·9 | 137·8 | 24·00 | 265·00 |
| 23 | 95·3 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 289·00 |
| 24 | 95·1 | ·690 | 65·62 | 11·1 | 11·1 | .......... | 13·7 | 137·8 | 24·00 | 313·00 |
| *25 | 95·2 | ·687 | 65·40 | 11·0 | 11·0 | .......... | 13 5 | 138·6 | 24·00 | 337·00 |
| 26 | 95·1 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 21·00 | 358·00 |
| *27 | 94·9 | ·682 | 64·72 | 10·4 | 10·4 | .......... | 12 8 | 139·2 | 24·00 | 382·00 |
| *28 | 95·1 | ·681 | 64·76 | 9·7 | 9·7 | .......... | 11·9 | 139·6 | 24·00 | 406·00 |
| *29 | 95·3 | ·684 | 65·18 | 9·5 | 9·5 | .......... | 11·7 | 139·3 | 24·00 | 430·00 |
| 30 | 95·1 | ·683 | 64·95 | 12·6 | 12·6 | .......... | 15·5 | 139·2 | 24·00 | 454·00 |
| May. | | | | | | | | | | |
| 1 | 95·3 | ·682 | 64·99 | 12·2 | 12·2 | .......... | 15·0 | 139·7 | 24·00 | 478·00 |
| 2 | 95·1 | ·680 | 64·66 | 11·6 | 11·6 | .......... | 14·3 | 139·9 | 24 00 | 502·00 |
| 3 | 95·1 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 526·00 |
| 4 | 95·1 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 550.00 |
| 5 | 95·1 | ·678 | 64·47 | 11·8 | 11·8 | .......... | 14·5 | 140·3 | 24·00 | 574·00 |
| 6 | 94·9 | ·674 | 63·96 | 11·4 | 11·4 | .......... | 14·0 | 140·8 | 23·30 | 597·30 |
| 7 | 95·0 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 621·30 |
| 8 | 95·3 | ·678 | 64·61 | 11·7 | 11·7 | .......... | 14·4 | 140·6 | 24·00 | 645·30 |
| 9 | 95·2 | ·676 | 64·36 | 11·7 | 11·7 | .......... | 14·4 | 140·8 | 24 00 | 669·30 |
| 10 | 95·1 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 693·30 |
| 11 | 95·0 | ·674 | 64·03 | 11·0 | 11·0 | .......... | 13·5 | 140·9 | 24·00 | 717·30 |
| 12 | 94·9 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 741·30 |
| 13 | 95·3 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 23·30 | 765·00 |
| 14 | 95·1 | ·674 | 64·09 | 9·8 | 9·8 | .......... | 12·1 | 141·1 | 24·00 | 789·00 |
| 15 | 95·4 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 813·00 |
| 16 | 95·2 | ·675 | 64·26 | 11·0 | 11·0 | .......... | 13.5 | 141·0 | 24·00 | 837·00 |
| 17 | 95·3 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 861·00 |
| 18 | 95·0 | ·668 | 63·46 | 11·0 | 11·0 | .......... | 13·5 | 142·2 | 24·00 | 885·00 |
| 19 | 95·0 | ·668 | 63·46 | 9·5 | 9·5 | .......... | 11·7 | 142·2 | 24·00 | 909·00 |
| 20 | 94.9 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 933·00 |
| 21 | 95·0 | ·666 | 63·26 | 10·7 | 10·7 | .......... | 13·2 | 142·6 | 24·00 | 957·00 |
| 22 | 95·3 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 981·00 |
| 23 | 94·8 | ·663 | 62·85 | 9·6 | 9·6 | .......... | 11·8 | 143·0 | 24·00 | 1,005·00 |
| 24 | 95·0 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 1,029·00 |
| *25 | 95·1 | ·666 | 63·33 | 7·5 | 7·5 | .......... | 9·2 | 142·9 | 24·00 | 1,053·00 |
| 26 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 11·30 | 1,064·30 |
| 28 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | .......... | .......... | .......... |

Resistance Cold. 257. Discoloration, 2½.

## *Edison Lamp, No. 10, 97 Volts.*

(Reduction Factor, 0·98. Resistance Cold, 246.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 97·8 | ·714 | 69·83 | 14·92 | 14·58 | 4·79 | 18·54 | 137·0 | 0·30 | 0·30 |
| 11 | ........ | ........ | ........ | 16·8 | 16·5 | ........ | 21·0 | ........ | 3·45 | 4·15 |
| 12 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 28·15 |
| 13 | 96·2 | ·689 | 66·28 | 12·8 | 12·5 | ........ | 15·9 | 139·6 | 24·00 | 52·15 |
| 14 | 97·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 76·15 |
| 15 | 96·3 | ·687 | 66·16 | 13·5 | 13·2 | ........ | 16·8 | 140·2 | 24·00 | 100·15 |
| 16 | 98·2 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 124·15 |
| 17 | 96·5 | ·688 | 66·40 | 12·8 | 12·6 | ........ | 16·0 | 140·3 | 24·00 | 148·15 |
| 18 | 95·7 | ·685 | 65·56 | 13·4 | 13·1 | ........ | 16·6 | 139·7 | 24·00 | 172·15 |
| 19 | 97·8 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 196·15 |
| 20 | 96·1 | ·683 | 65·61 | 12·3 | 12·1 | ........ | 15·4 | 140·7 | 20·45 | 217·00 |
| 21 | 97·2 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 241·00 |
| 22 | 96·8 | ·685 | 66·31 | 12·3 | 12·1 | ........ | 15·4 | 141·3 | 24·00 | 265·00 |
| 23 | 97·2 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 289·00 |
| 24 | 97·0 | ·683 | 66·25 | 11·7 | 11·5 | ........ | 14·6 | 142·0 | 24·00 | 313·00 |
| *25 | 97·2 | ·685 | 66·58 | 10·9 | 10·7 | ........ | 13·6 | 141·9 | 24·00 | 337·00 |
| 26 | 96·8 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 21·00 | 358·00 |
| *27 | 96·7 | ·681 | 65·85 | 10·5 | 10·3 | ........ | 13·1 | 142·0 | 24·00 | 382·00 |
| *28 | 97·0 | ·683 | 66·25 | 9·6 | 9·4 | ........ | 11·9 | 142·0 | 24·00 | 406·00 |
| *29 | 96·8 | ·682 | 66·01 | 9·6 | 9·4 | ........ | 11·9 | 141·9 | 24·00 | 430·00 |
| 30 | 96·7 | ·682 | 65·95 | 11·7 | 11·5 | ........ | 14·6 | 141·8 | 24·00 | 454·00 |
| May. | | | | | | | | | | |
| 1 | 97·3 | ·682 | 66·35 | 12·2 | 12·0 | ........ | 15·2 | 142·7 | 24·00 | 478·00 |
| 2 | 97·0 | ·681 | 66·05 | 12·0 | 11·8 | ........ | 15 0 | 142·4 | 24·00 | 502·00 |
| 3 | 97·1 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 526·00 |
| 4 | 97·1 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 550·00 |
| 5 | 97·0 | ·682 | 66·15 | 12·0 | 11·8 | ........ | 15·0 | 142·2 | 24·00 | 574·00 |
| 6 | 97·1 | ·678 | 65·83 | 11·4 | 11·2 | ........ | 14·2 | 143·2 | 23·30 | 597·30 |
| 7 | 96·9 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 621·30 |
| 8 | 96·9 | ·677 | 65·60 | 11·8 | 11·6 | ........ | 14·7 | 143·1 | 24·00 | 645·30 |
| 9 | 97·1 | ·677 | 65·74 | 11·6 | 11·4 | ........ | 14·5 | 143·4 | 24·00 | 669·30 |
| 10 | 96·9 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 693·30 |
| 11 | 96·9 | ·675 | 65·40 | 11·1 | 10·9 | ........ | 13·8 | 143·6 | 24·00 | 717·30 |
| 12 | 97·1 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 741·30 |
| 13 | 97·3 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 23·30 | 765·00 |
| 14 | 97·2 | ·676 | 65·70 | 10·3 | 10·0 | ........ | 12·7 | 143·8 | 24·00 | 789·00 |
| 15 | 97·1 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 813·00 |
| 16 | 97·2 | ·675 | 65·61 | 11·2 | 11·0 | ........ | 14·0 | 144·0 | 24·00 | 837·00 |
| 17 | 87·3 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 861·00 |
| 18 | 97·2 | ·674 | 65·51 | 11·5 | 11·3 | ........ | 14·4 | 144·2 | 24·00 | 885·00 |
| 19 | 97·1 | ·672 | 65·25 | 10·2 | 10·0 | ........ | 12·7 | 144·5 | 24·00 | 909·00 |
| 20 | 97·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 933·00 |
| 21 | 97·0 | ·669 | 64·89 | 10·8 | 10·6 | ........ | 13·5 | 145·0 | 24·00 | 957·00 |
| 22 | 97·6 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 981·00 |
| 23 | 96·6 | ·664 | 64·14 | 9·7 | 9·5 | ........ | 12·1 | 145·5 | 24·00 | 1,005·00 |
| 24 | 96·8 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 1,029·00 |
| *25 | 96·9 | ·667 | 64·63 | 7·5 | 7·4 | ........ | 9·4 | 145·3 | 24·00 | 1,053·00 |
| 26 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 11.30 | 1,064·30 |
| 28 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ |

Resistance Cold, 259. Discoloration, 2.

## *Edison Lamp, No. 11, 98 Volts.*

(Reduction Factor, 0·91. Resistance Cold, 250.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal, | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885 April. | 98·7 | ·711 | 70·18 | 18·25 | 16·66 | 4·21 | 20·98 | 138·8 | 0·45 | 0·45 |
| 11 | ........ | ........ | ........ | 16·6 | 15·1 | ........ | 19·0 | ........ | 3·45 | 4·30 |
| 12 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 28·30 |
| 13 | 97·5 | ·692 | 67·47 | 14·5 | 13·2 | ........ | 16·5 | 140·9 | 24·00 | 52·30 |
| 14 | 98·3 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 76·30 |
| 15 | 97·6 | ·693 | 67·63 | 16·7 | 15·2 | ........ | 19·2 | 140·8 | 24·00 | 100·30 |
| 16 | 98·9 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 124·30 |
| 17 | 97·7 | ·689 | 67·41 | 14·8 | 13·5 | ........ | 17·0 | 141·6 | 24·00 | 148·30 |
| 18 | 97·8 | ·687 | 67·19 | 16·6 | 15·1 | ........ | 19·0 | 142·4 | 24·00 | 172·30 |
| 19 | 99·6 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 196·30 |
| 20 | 97·0 | ·689 | 65·96 | 14·5 | 13·2 | ........ | 16·6 | 142·6 | 20·45 | 217·15 |
| 21 | 97·7 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 241·15 |
| 22 | 97·8 | ·689 | 66·50 | 14·5 | 13·2 | ........ | 16·6 | 143·8 | 24·00 | 265·15 |
| 23 | 97·9 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 289·15 |
| 23 | 97·5 | ·675 | 65·81 | 12·5 | 11·4 | ........ | 14·4 | 144·4 | 24·00 | 313·15 |
| *25 | 98·0 | ·674 | 66·05 | 11·5 | 10·5 | ........ | 13·2 | 145·4 | 24·00 | 337·15 |
| 26 | 98·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 21·00 | 358·15 |
| *27 | 97·6 | ·672 | 65·58 | 11·8 | 10·7 | ........ | 13·5 | 145·2 | 24·00 | 382·15 |
| *28 | 97·8 | ·673 | 65·82 | 10·6 | 9·6 | ........ | 12·1 | 145·3 | 24 00 | 406·15 |
| *29 | 97·8 | ·667 | 65·23 | 10·1 | 9·2 | ........ | 11·6 | 146·6 | 24·00 | 430·15 |
| 30 | 97·6 | ·673 | 65·68 | 13·2 | 12·0 | ........ | 15·5 | 145·0 | 24.00 | 454·15 |
| May, | | | | | | | | | | |
| 1 | 97·5 | ·667 | 65·03 | 13·1 | 11·9 | ........ | 15·0 | 146·2 | 24·00 | 478·15 |
| 2 | 97·7 | ·668 | 65·26 | 12·6 | 11·5 | ........ | 14·5 | 146·3 | 24·00 | 502·15 |
| 3 | 98·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 526·15 |
| 4 | 98·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 550·15 |
| 5 | 97·9 | ·668 | 65·39 | 13·0 | 11·8 | ........ | 14·9 | 146·6 | 24·00 | 574·15 |
| 6 | 98·0 | ·666 | 65·26 | 12·1 | 11·0 | ........ | 13·9 | 147·2 | 23·30 | 597·45 |
| 7 | 97·6 | ·662 | 64·61 | 12·3 | 11·2 | ........ | 14·1 | 147·4 | 24·00 | 621·45 |
| 8 | 98·1 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 645·45 |
| 9 | 97·9 | ·664 | 65·01 | 12·4 | 11·3 | ........ | 14·2 | 147·4 | 24·00 | 669·45 |
| 10 | 97·7 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 693·45 |
| 11 | 97·8 | ·662 | 64·74 | 11·5 | 10·5 | ........ | 13·2 | 147·7 | 24·00 | 717·45 |
| 12 | 97·8 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 741·45 |
| 13 | 97·9 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 23·30 | 765·15 |
| 14 | 98·0 | ·662 | 64·87 | 11·5 | 10·5 | ........ | 13·2 | 148·0 | 24·00 | 789·15 |
| 15 | 98·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 813·15 |
| 16 | 97·6 | ·659 | 64·31 | 12·1 | 11·0 | ........ | 13·9 | 148·1 | 24·00 | 837·15 |
| 17 | 97·9 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 861·15 |
| 18 | 97·7 | ·660 | 64·48 | 12·0 | 10·9 | ........ | 13·7 | 148·0 | 24·00 | 885·15 |
| 19 | 97·8 | ·658 | 64·35 | 10·3 | 9·4 | ........ | 11·8 | 148·6 | 24·00 | 909·15 |
| 20 | 97·9 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 933·15 |
| 21 | 97·8 | ·656 | 64·15 | 11·4 | 10·4 | ........ | 13·1 | 149·1 | 24·00 | 957·15 |
| 22 | 97·9 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 981·15 |
| 23 | 97·6 | ·653 | 63·73 | 10·4 | 9·5 | ........ | 12·0 | 149·5 | 24·00 | 1,005·15 |
| 24 | 97·9 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 1,029·15 |
| *25 | 97·9 | ·659 | 64·51 | 8·0 | 7·3 | ........ | 9·2 | 148·6 | 24·00 | 1,053·15 |
| 26 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 11·30 | 1,064·45 |
| 28 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ |

Resistance Cold, 269. Discoloration, 3.

## *Edison Lamp, No. 12, 98 Volts.*

(Reduction Factor, 0·93. Resistance Cold, 254.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles, Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 98·8 | ·686 | 67·77 | 14·72 | 13·76 | 4·92 | 17·48 | 144·0 | 1·00 | 1·00 |
| 11 | ........ | ........ | ........ | 16·4 | 15·3 | ........ | 19·4 | ........ | 3·45 | 4·45 |
| 12 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 28·45 |
| 13 | 97·2 | ·669 | 65·02 | 13·0 | 12·1 | ........ | 15·4 | 145·3 | 24·00 | 52·45 |
| 14 | 98·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 76·45 |
| 15 | 97·4 | ·671 | 65·35 | 14·7 | 13·7 | ........ | 17·4 | 145·2 | 24·00 | 100·45 |
| 16 | 98·1 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 124·45 |
| 17 | 97·5 | ·669 | 65·23 | 12·7 | 11·8 | ........ | 15·0 | 145·7 | 24·00 | 148·45 |
| 18 | 97·6 | ·671 | 65·49 | 14·7 | 13·7 | ........ | 17·4 | 145·5 | 24·00 | 172·45 |
| 19 | 99·5 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 196·45 |
| 20 | 96·9 | ·664 | 64·34 | 13·2 | 12·3 | ........ | 15·6 | 145·9 | 20·45 | 217·30 |
| 21 | 98·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 241·30 |
| 22 | 97·9 | ·669 | 65·50 | 12·9 | 12·0 | ........ | 15·2 | 146·3 | 24·00 | 265·30 |
| 23 | 98·2 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 289·30 |
| 24 | 97·9 | ·667 | 65·30 | 12·0 | 11·2 | ........ | 14·2 | 146·8 | 24·00 | 313·30 |
| *25 | 98·1 | ·666 | 65·33 | 11·7 | 10·9 | ........ | 13·8 | 147·3 | 24·00 | 337·30 |
| 26 | 97·9 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 21·00 | 358·30 |
| *27 | 97·8 | ·668 | 65·33 | 11·8 | 11·0 | ........ | 14·0 | 146·4 | 24·00 | 382·30 |
| *28 | 98·0 | ·666 | 65·26 | 9·7 | 9·0 | ........ | 11·4 | 147·2 | 24·00 | 406·30 |
| *29 | 97·8 | .660 | 64·54 | 9·9 | 9·2 | ........ | 11·7 | 148·2 | 24·00 | 430·30 |
| 30 | 97·8 | .664 | 64·94 | 13·0 | 12·1 | ........ | 15·4 | 147·3 | 24·00 | 454·30 |
| May. | | | | | | | | | | |
| 1 | 98·0 | ·663 | 64·97 | 12·6 | 11·7 | ........ | 14·9 | 147·8 | 24·00 | 478·30 |
| 2 | 97·7 | ·665 | 64·97 | 12·3 | 11·4 | ........ | 14·5 | 146·9 | 24·00 | 502·30 |
| 3 | 97·8 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 526·30 |
| 4 | 97·7 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 550·30 |
| 5 | 97·9 | ·660 | 64·61 | 13·2 | 12·3 | ........ | 15·6 | 148·3 | 24·00 | 574·30 |
| 6 | 97·8 | ·658 | 64·35 | 11·4 | 10·6 | ........ | 13·5 | 148·6 | 23·30 | 598·00 |
| 7 | 97·6 | ·657 | 64·12 | 12·1 | 11·3 | ........ | 14·4 | 148·6 | 24·00 | 622·00 |
| 8 | 97·8 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 646·00 |
| 9 | 97·8 | ·658 | 64·35 | 12·8 | 11·9 | ........ | 15·1 | 148·6 | 24·00 | 670·00 |
| 10 | 97·6 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 694·00 |
| 11 | 97·8 | ·659 | 64·45 | 11·6 | 10·8 | ........ | 13·7 | 148·4 | 24·00 | 718·00 |
| 12 | 97·7 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 742·00 |
| 13 | 98·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 23·30 | 765·30 |
| 14 | 97·9 | ·656 | 64·22 | 11·1 | 10·3 | ........ | 13·1 | 149·2 | 24·00 | 789·30 |
| 15 | 97·9 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 813·30 |
| 16 | 97·7 | ·653 | 63·79 | 11·5 | 10·7 | ........ | 13·6 | 149·6 | 24·00 | 837·30 |
| 17 | 97·8 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 861·30 |
| 18 | 97·8 | ·653 | 63·86 | 11·9 | 11·1 | ........ | 14·1 | 149·8 | 24·00 | 885·30 |
| 19 | 97·7 | ·654 | 63·89 | 10·1 | 9·4 | ........ | 11·9 | 149·4 | 24·00 | 909·30 |
| 20 | 97·6 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 933·30 |
| 21 | 98·0 | ·653 | 63·99 | 11·5 | 10·7 | ........ | 13·6 | 150·1 | 24·00 | 957·30 |
| 22 | 98·1 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 981·30 |
| 23 | 97·6 | ·649 | 63·34 | 10·7 | 10·0 | ........ | 12·7 | 150·4 | 24·00 | 1,005·30 |
| 24 | 97·9 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 1,029·30 |
| *25 | 97·8 | ·652 | 63·76 | 8·1 | 7·5 | ........ | 9·5 | 150·0 | 24·00 | 1,053·30 |
| 26 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 11·30 | 1,065·00 |
| 28 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ |

Resistance Cold 268. Discoloration, 2.

## *Edison Lamp, No. 13, 96 Volts.*

(Reduction Factor, 0·93. Resistance Hot, 235.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Mean Horizontal Candles. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 96·7 | ·723 | 69·91 | 16·67 | 15·44 | 4·52 | 19·00 | 133·7 | 0·30 | 0·30 |
| 11 | ... | ... | ... | 15·6 | 14·5 | ... | 17·8 | ... | 3·45 | 4·15 |
| 12 | ... | ... | ... | ... | ... | ... | ... | ... | 24·00 | 28·15 |
| 13 | 95·0 | ·700 | 66·50 | 14·0 | 13·0 | ... | 16·0 | 135·7 | 24·00 | 52·15 |
| 14 | 95·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 76·15 |
| 15 | 95·4 | ·705 | 67·26 | 15·1 | 14·0 | ... | 17·2 | 135·3 | 24·00 | 100·15 |
| 16 | 95·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 124·15 |
| 17 | 95·4 | ·710 | 67·73 | 14·3 | 13·3 | ... | 16·4 | 134·4 | 24·00 | 148·15 |
| 18 | 95·9 | ·710 | 68·09 | 16·3 | 15·2 | ... | 18·7 | 135·1 | 24·00 | 172·15 |
| 19 | 97·4 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 196·15 |
| 20 | 95·2 | ·705 | 67·12 | 13·4 | 12·5 | ... | 15·4 | 135·0 | 20·45 | 217·00 |
| 21 | 96·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 241·00 |
| 22 | 95·9 | ·706 | 67·70 | 13·8 | 12·8 | ... | 15·7 | 135·8 | 24·00 | 265·00 |
| 23 | 96·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 289·00 |
| 24 | 95·8 | ·702 | 67·25 | 12·2 | 11·3 | ... | 13·9 | 136·5 | 24·00 | 313·00 |
| *25 | 96·0 | ·703 | 67·48 | 11·5 | 10·7 | ... | 13·2 | 136·6 | 24·00 | 337·00 |
| 26 | 95·9 | ... | ... | ... | ... | ... | ... | ... | 21·00 | 358·00 |
| *27 | 95·9 | ·702 | 67·32 | 11·6 | 10·8 | ... | 13·3 | 136·6 | 24·00 | 382·00 |
| *28 | 95·9 | ·700 | 67·13 | 10·5 | 9 8 | ... | 12·1 | 137·0 | 24·00 | 406·00 |
| *29 | 95·8 | ·700 | 67·06 | 10·1 | 9·4 | ... | 11·6 | 136·9 | 24·00 | 430·00 |
| 30 | 95·8 | ·702 | 67·25 | 12·9 | 12·0 | ... | 14·8 | 136·5 | 24·00 | 454·00 |
| May. | | | | | | | | | | |
| 1 | 96·0 | ·698 | 67·00 | 12·5 | 11·6 | ... | 14·3 | 137·5 | 24·00 | 478·00 |
| 2 | 95·8 | ·699 | 66·96 | 12·4 | 11.5 | ... | 14·1 | 137·1 | 24·00 | 502·00 |
| 3 | 95·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 526·00 |
| 4 | 95·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 550·00 |
| 5 | 96·0 | ·700 | 67·20 | 12·7 | 11·8 | ... | 14·5 | 137·1 | 24·00 | 574·00 |
| 6 | 96·3 | ·699 | 67·31 | 11·8 | 11·0 | ... | 13·5 | 137·8 | 23·30 | 597·30 |
| 7 | 96·0 | ·696 | 66·81 | 12·3 | 11·4 | ... | 14·0 | 137·9 | 24·00 | 621·30 |
| 8 | 96·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 645·30 |
| 9 | 96·2 | ·697 | 67·05 | 12·5 | 11·6 | ... | 14·3 | 138·0 | 24·00 | 669·30 |
| 10 | 96·1 | ... | ... | ... | ... | ... | ... | ... | 24 00 | 693·30 |
| 11 | 96·0 | ·695 | 66·71 | 11·5 | 10·7 | ... | 13 2 | 138·1 | 24·00 | 717·30 |
| 12 | 96·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 741·30 |
| 13 | 96 1 | ... | ... | ... | ... | ... | ... | ... | 23·30 | 765·00 |
| 14 | 96·1 | ·695 | 66·78 | 11·4 | 10·6 | ... | 13·0 | 138·3 | 24·00 | 789·00 |
| 15 | 96·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 813·00 |
| 16 | 96·2 | ·693 | 66·66 | 11·6 | 10.8 | ... | 13·3 | 138·8 | 24·00 | 837·00 |
| 17 | 96·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 861·00 |
| 18 | 96·2 | ·691 | 66·47 | 12·0 | 11·2 | ... | 13·8 | 139·2 | 24·00 | 885·00 |
| 19 | 96·1 | ·693 | 66·59 | 9·8 | 9·1 | ... | 11·2 | 138·7 | 24·00 | 909·00 |
| 20 | 96·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 933·00 |
| 21 | 96·2 | ·689 | 66·28 | 11·4 | 10·6 | ... | 13·0 | 139·6 | 24·00 | 957·00 |
| 22 | 96·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 981·00 |
| 23 | 95·8 | ·687 | 65·81 | 10·6 | 9·9 | ... | 12·2 | 139·4 | 24·00 | 1,005·00 |
| 24 | 96·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 1,029·00 |
| *25 | 96·1 | ·689 | 66·21 | 8·3 | 7·7 | ... | 9·5 | 139·5 | 24·00 | 1,053·00 |
| 26 | ... | ... | ... | ... | ... | ... | ... | ... | 11·30 | 1,064·30 |
| 28 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

Resistance Cold, 247. Discoloration, 2½.

## *Edison Lamp, No. 14, 96 Volts.*

(Reduction Factor, 0·94. Resistance Cold, 245.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 96·7 | ·707 | 68·37 | 16·63 | 15·62 | 4·37 | 19·70 | 136·8 | 0·30 | 0·30 |
| 11 | ...... | ...... | ...... | 17·4 | 16·4 | ...... | 20·7 | ...... | 3·45 | 4·15 |
| 12 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 28·15 |
| 13 | 95·3 | ·690 | 65·76 | 14·0 | 13·2 | ...... | 16·6 | 138·1 | 24·00 | 52·15 |
| 14 | 96·2 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 76·15 |
| 15 | 95·7 | ·696 | 66·61 | 15·2 | 14·3 | ...... | 18·0 | 137·5 | 24·00 | 100·15 |
| 16 | 96·3 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 124·15 |
| 17 | 95·9 | ·693 | 66·46 | 14·4 | 13·6 | ...... | 17·1 | 138·4 | 24·00 | 148·15 |
| 18 | 96·3 | ·697 | 67·12 | 15·7 | 14·8 | ...... | 18·6 | 138·2 | 24·00 | 172·15 |
| 19 | 97·6 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 196·15 |
| 20 | 95·3 | ·687 | 65·47 | 13·1 | 12·3 | ...... | 15·5 | 138·7 | 20·45 | 217·00 |
| 21 | 96·9 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 241·00 |
| 22 | 95·9 | ·685 | 65·69 | 13·1 | 12·3 | ...... | 15·5 | 140·0 | 24·00 | 265·00 |
| 23 | 96·3 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 289·90 |
| 24 | 96·1 | ·681 | 65·44 | 12·0 | 11·3 | ...... | 14·2 | 141·1 | 24·00 | 313·00 |
| *25 | 96·2 | ·688 | 65·18 | 11·3 | 10·6 | ...... | 13·4 | 139·8 | 24·00 | 337·00 |
| 26 | 96·2 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 21·00 | 358·00 |
| *27 | 96·0 | ·680 | 65·28 | 11·0 | 10·3 | ...... | 13·0 | 141·2 | 24·00 | 382·00 |
| *28 | 96·2 | ·680 | 65·41 | 10·1 | 9·5 | ...... | 12·0 | 141·5 | 24·00 | 406·00 |
| *29 | 96·3 | ·681 | 65·58 | 10·3 | 9·7 | ...... | 12 2 | 141·4 | 24·00 | 430·00 |
| 30 | 96·4 | ·680 | 65·55 | 12·9 | 12·1 | ...... | 15.2 | 141·8 | 24·00 | 454·00 |
| May. | | | | | | | | | | |
| 1 | 96·1 | ·677 | 65·06 | 12·4 | 11·7 | ...... | 14·7 | 141·9 | 24·00 | 478·00 |
| 2 | 96·1 | ·679 | 65·25 | 11·9 | 11·2 | ...... | 14·1 | 141·5 | 24·00 | 502·00 |
| 3 | 96·1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 526·00 |
| 4 | 96·1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 550·00 |
| 5 | 96·1 | ·677 | 65·06 | 12·3 | 11·6 | ...... | 14·6 | 141·9 | 24·00 | 574·00 |
| 6 | 96·3 | ·674 | 64·90 | 11·5 | 10·8 | ...... | 13·6 | 142·9 | 23·30 | 597·30 |
| 7 | 96·0 | ·670 | 64·31 | 12·0 | 11·3 | ...... | 14·2 | 143·3 | 24·00 | 621·30 |
| 8 | 96·1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 645·30 |
| 9 | 96·3 | ·671 | 64·62 | 12·3 | 11·6 | ...... | 14·6 | 143·5 | 24·00 | 669·30 |
| 10 | 96.3 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 693·30 |
| 11 | 96·0 | ·669 | 64 22 | 11·3 | 10·6 | ...... | 13·4 | 143·5 | 24·00 | 717·30 |
| 12 | 96·0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 741·30 |
| 13 | 96·3 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 23·30 | 765·00 |
| 14 | 96·1 | ·670 | 64·38 | 10·8 | 10·2 | ...... | 12·9 | 143·4 | 24·00 | 789·00 |
| 15 | 96·3 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 813·00 |
| 16 | 96·0 | ·667 | 64·03 | 11·0 | 10·3 | ...... | 13·0 | 143·9 | 24·00 | 837·00 |
| 17 | 96·5 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 861·00 |
| 18 | 95·7 | ·663 | 63·44 | 11·1 | 10·4 | ...... | 13·1 | 144·3 | 24·00 | 885·00 |
| 19 | 95·7 | ·662 | 63·35 | 9·4 | 8·8 | ...... | 11·1 | 144·6 | 24·00 | 909·00 |
| 20 | 95·8 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 933·00 |
| 21 | 95·7 | ·660 | 63·16 | 10·6 | 10·0 | ...... | 12·6 | 145·0 | 24·00 | 957·00 |
| 22 | 96·0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 981·00 |
| 23 | 95·7 | ·658 | 62·97 | 9·7 | 9·1 | ...... | 11·5 | 145·4 | 24·00 | 1,005·00 |
| 24 | 95·9 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 1,029·00 |
| *25 | 95·8 | ·659 | 63·13 | 7·7 | 7·2 | ...... | 9·1 | 145·4 | 24·00 | 1,053·00 |
| 26 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 11·30 | 1,064·00 |
| 28 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |

Resistance Cold, 260. Discoloration, 3.

## *Edison Lamp, No. 15, 99 Volts.*

(Reduction Factor, 1·09. Resistance Cold, 2·55.)

| Date. | Volts. | Amperes. | Watts. | Candles Observed | Candles Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 99·7 | ·692 | 68·99 | 14·30 | 15·65 | 4·40 | 19·74 | 144·1 | 0·30 | 0·30 |
| 11 | ........... | ........... | ........... | 14·4 | 15·7 | ........... | 19·8 | ........... | 3·45 | 4·15 |
| 12 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 28·15 |
| 13 | 98·1 | ·662 | 64·94 | 11·2 | 12·3 | ........... | 15·5 | 148·2 | 24·00 | 52·15 |
| 14 | 99·1 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 76·15 |
| 15 | 98·5 | ·667 | 65·70 | 12·4 | 13·5 | ........... | 17·0 | 147·7 | 24·00 | 100·15 |
| 16 | 99·0 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 124·15 |
| 17 | 98·9 | ·671 | 66·36 | 11·5 | 12·5 | ........... | 15·8 | 147·4 | 24·00 | 148·15 |
| 18 | 98·9 | ·674 | 66·65 | 12·5 | 13·6 | ........... | 17·1 | 146·7 | 24·00 | 172·15 |
| 19 | 100·1 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 196·15 |
| 20 | 98·1 | ·666 | 65·34 | 11·2 | 12·2 | ........... | 15·4 | 147·3 | 20·45 | 217·00 |
| 21 | 99·8 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 241·00 |
| 22 | 98·8 | ·665 | 65·71 | 11·2 | 12·2 | ........... | 15·4 | 148·6 | 24·00 | 265·00 |
| 23 | 99·4 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 289·00 |
| 24 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 6·00 | 295·00 |

Carbon broke at side of loop 6.00 A. M., April 24, 1885. Discoloration, 2.

## *Edison Lamp, No. 16, 95 Volts.*

(Reduction Factor, 0·79. Resistance Cold, 239.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 95·7 | ·714 | 68·33 | 20·30 | 16·09 | 4·21 | 20·26 | 134·0 | 0·30 | 0·30 |
| 11 | ...... | ...... | ...... | 19·0 | 15·0 | ...... | 18·9 | ...... | 3·45 | 4·15 |
| 12 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 28·15 |
| 13 | 94·1 | ·689 | 64·84 | 16·2 | 12·8 | ...... | 16·1 | 136·6 | 24·00 | 52·15 |
| 14 | 95·2 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 76·15 |
| 15 | 94·9 | ·696 | 66·05 | 17·2 | 13·6 | ...... | 17·1 | 136·4 | 24·00 | 100·15 |
| 16 | 95·0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 124·15 |
| 17 | 95·1 | ·696 | 66·19 | 15·7 | 12·4 | ...... | 15·6 | 136·6 | 24·00 | 148·15 |
| 18 | 95·8 | ·699 | 66·96 | 17·1 | 13·5 | ...... | 17·0 | 137·1 | 24·00 | 172·15 |
| 19 | 95·9 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 196·15 |
| 20 | 94·2 | ·689 | 64·90 | 15·7 | 12·4 | ...... | 15·6 | 136·7 | 20·45 | 217·00 |
| 21 | 96·0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 241·00 |
| 22 | 95·0 | ·687 | 65·27 | 15·1 | 11·9 | ...... | 15·0 | 138·3 | 24·00 | 265·00 |
| 23 | 95·2 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 289·00 |
| 24 | 95·2 | ·685 | 65·21 | 14·1 | 11·1 | ...... | 14·0 | 139·0 | 24·00 | 313·00 |
| *25 | 95·1 | ·684 | 65·04 | 12·7 | 10·0 | ...... | 12·6 | 139·0 | 24·00 | 337·00 |
| 26 | 95·2 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 21·00 | 358·00 |
| *27 | 95·1 | ·682 | 64·85 | 12·8 | 10·1 | ...... | 12·7 | 139·4 | 24·00 | 382·00 |
| *28 | 95·0 | ·682 | 64·79 | 11·6 | 9·2 | ...... | 11·7 | 139·3 | 24·00 | 406·00 |
| *29 | 95·1 | ·682 | 64·85 | 11·5 | 9·1 | ...... | 11·5 | 139·4 | 24·00 | 430·00 |
| 30 | 95·1 | ·684 | 65·04 | 14·6 | 11·5 | ...... | 14·5 | 139·0 | 24·00 | 454·00 |
| May. | | | | | | | | | | |
| 1 | 95·0 | ·678 | 64·41 | 14·3 | 11·3 | ...... | 14·2 | 140·1 | 24·00 | 478·00 |
| 2 | 95·0 | ·678 | 64·41 | 13·9 | 11·0 | ...... | 13·9 | 140·1 | 24·00 | 502·00 |
| 3 | 95·1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 526·00 |
| 4 | 95·1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 550·00 |
| 5 | 95·0 | ·679 | 64·50 | 14·8 | 11·7 | ...... | 14·7 | 139·9 | 24·00 | 574·00 |
| 6 | 95·0 | ·677 | 64·31 | 12·9 | 10·2 | ...... | 12·9 | 140·3 | 23·30 | 597·30 |
| 7 | 94·9 | ·670 | 63·58 | 13·5 | 10·7 | ...... | 13·5 | 141·6 | 24·00 | 621·30 |
| 8 | 95·0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 645·30 |
| 9 | 95·1 | ·674 | 64·10 | 13·7 | 10·8 | ...... | 13·6 | 141·1 | 24·00 | 669·30 |
| 10 | 94·9 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 693·30 |
| 11 | 94·9 | ·671 | 63·67 | 12·5 | 9·9 | ...... | 12·5 | 141·4 | 24·00 | 717·30 |
| 12 | 94·8 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 23·00 | 741·30 |
| 13 | 95·1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 23·30 | 765·00 |
| 14 | 95·0 | ·671 | 63·74 | 12·1 | 9·6 | ...... | 12·1 | 141·6 | 24·00 | 789·00 |
| 15 | 95·3 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 813·00 |
| 16 | 94·9 | ·670 | 63·58 | 13·1 | 10·3 | ...... | 13·0 | 141·6 | 24·00 | 837·00 |
| 17 | 95·3 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 861·00 |
| 18 | 95·0 | ·669 | 63·55 | 12·7 | 10·0 | ...... | 12·6 | 142·0 | 24·00 | 885·00 |
| 19 | 94·9 | ·669 | 63·48 | 11·2 | 8·8 | ...... | 11·1 | 141·9 | 24·00 | 909·00 |
| 20 | 94·7 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 933·00 |
| 21 | 95·2 | ·667 | 63·50 | 12·0 | 9·5 | ...... | 12·0 | 142·7 | 24·00 | 957·00 |
| 22 | 95·1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 981·00 |
| 23 | 94·7 | ·664 | 62·88 | 11·5 | 9·1 | ...... | 11·5 | 142·6 | 24·00 | 1,005·00 |
| 24 | 95·0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 1,029·00 |
| *25 | 94·8 | ·665 | 63·04 | 8·9 | 7·0 | ...... | 8·8 | 142·6 | 24·00 | 1,053·00 |
| 26 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 11·30 | 1,064·30 |
| 28 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |

Resistance Cold, 256. Discoloration, 2½.

## *Edison Lamp, No. 17, 98 Volts.*

(Reduction Factor, 0·92. Resistance Cold, 259.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1882. April. | 98·8 | ·701 | 69·26 | 17·98 | 16·61 | 4·17 | 21·10 | 140·9 | 1·00 | 1·00 |
| 11 | ........ | ........ | ........ | 16·8 | 15·5 | ........ | 19·7 | ........ | 3·45 | 4·45 |
| 12 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 28·45 |
| 13 | 96·9 | ·679 | 65·79 | 15·1 | 13·9 | ........ | 17·7 | 142·7 | 24·00 | 52·45 |
| 14 | 98·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 76·45 |
| 15 | 97·6 | ·682 | 66·56 | 15·3 | 14·1 | ........ | 17·9 | 143·1 | 24·00 | 100·45 |
| 16 | 98·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 124·45 |
| 17 | 98·0 | ·685 | 67·13 | 14·7 | 13·5 | ........ | 17·1 | 143·1 | 24·00 | 148·45 |
| 18 | 98·4 | ·684 | 67·31 | 15·9 | 14·6 | ........ | 18·5 | 143·9 | 24·00 | 172·45 |
| 19 | 99·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 196·45 |
| 20 | 98·5 | ·681 | 67·08 | 15·1 | 13·9 | ........ | 17·7 | 144·6 | 20·45 | 217·30 |
| 21 | 99·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 241·30 |
| 22 | 98·1 | ·675 | 66·22 | 13·7 | 12·6 | ........ | 16·0 | 145·3 | 24·00 | 265·30 |
| 23 | 98·4 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 289·30 |
| 24 | 98·3 | ·670 | 65·86 | 12·6 | 11·6 | ........ | 14·7 | 146·7 | 24 00 | 313·30 |
| *25 | 98·5 | ·672 | 66·19 | 11·5 | 10·6 | ........ | 13·5 | 146·6 | 24·00 | 337·30 |
| 26 | 98·5 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 21·00 | 358·30 |
| *27 | 98·4 | ·666 | 65·53 | 11·3 | 10·4 | ........ | 13·2 | 147·8 | 24·00 | 382·30 |
| *28 | 97·8 | ·661 | 64·64 | 10·1 | 9·3 | ........ | 11·8 | 148·0 | 24·00 | 406·30 |
| *29 | 98·0 | ·661 | 64·77 | 9·6 | 8·8 | ........ | 11·2 | 148·3 | 24·00 | 430·30 |
| 30 | 98·1 | ·660 | 64·74 | 12·0 | 11·0 | ........ | 14·0 | 148·6 | 24·00 | 454·30 |
| May. | | | | | | | | | | |
| 1 | 98·0 | ·656 | 64·28 | 12·1 | 11·1 | ........ | 14·1 | 149·4 | 24·00 | 478·30 |
| 2 | 97·9 | ·655 | 64·12 | 11·5 | 10·6 | ........ | 13·5 | 149 5 | 24·00 | 502·30 |
| 3 | 97·9 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 526·30 |
| 4 | 98·1 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 550·30 |
| 5 | 97·8 | ·650 | 63·57 | 11·5 | 10·6 | ........ | 13·5 | 150·5 | 24·00 | 574·30 |
| 6 | 97·9 | ·651 | 63·73 | 10·7 | 9·8 | ........ | 12·4 | 150·4 | 23·30 | 598·00 |
| 7 | 97·7 | ·648 | 63·31 | 10·9 | 10·0 | ........ | 12·7 | 150·8 | 24·00 | 622·00 |
| 8 | 97·9 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 646·00 |
| 9 | 97·9 | ·648 | 63·44 | 11·7 | 10·8 | ........ | 13·7 | 151·1 | 24·00 | 670·00 |
| 10 | 97·8 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 694·00 |
| 11 | 97·7 | ·648 | 63·31 | 10·6 | 9·8 | ........ | 12·4 | 150·8 | 24·00 | 718·00 |
| 12 | 97·7 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 742·00 |
| 13 | 98·4 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 23·30 | 765·30 |
| 14 | 98·0 | ·647 | 63·40 | 10·5 | 9·7 | ........ | 12·3 | 151·5 | 24·00 | 789·30 |
| 15 | 97·9 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 813·30 |
| 16 | 97·7 | ·650 | 63·50 | 10·6 | 9·8 | ........ | 12·4 | 150·3 | 24·00 | 837·30 |
| 17 | 98·1 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 861·30 |
| 18 | 98·0 | ·644 | 63·11 | 10·8 | 9·9 | ........ | 12·6 | 152·2 | 24·00 | 885 30 |
| 19 | 97·8 | ·643 | 62·88 | 8·8 | 8·1 | ........ | 10·3 | 152·1 | 24·00 | 909·30 |
| 20 | 97·9 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 933·30 |
| 21 | 98·0 | ·640 | 62·72 | 10·3 | 9·5 | ........ | 12·1 | 153·1 | 24·00 | 957·30 |
| 22 | 98·1 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 981·30 |
| 23 | 97·6 | ·638 | 62·26 | 9·5 | 8·7 | ........ | 11·0 | 153·0 | 24·00 | 1,005·30 |
| 24 | 97·8 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 1,029·30 |
| *25 | 97·9 | ·639 | 62·55 | 7·5 | 6·9 | ........ | 8·8 | 153·2 | 24·00 | 1,053 30 |
| 26 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 11·30 | 1,065·00 |
| 28 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ |

Resistance Cold, 280. Discoloration, 3.

## *Edison Lamp, No. 18, 97 Volts.*

(Reduction Factor, 0·96. Resistance Cold, 242.)

| Date. | Volts. | Amperes. | Watts. | Candles. | | Watts per Spher. Cand. | Candles, Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Observed. | Spherical. | | | | | |
| 1885. April. | 97·7 | ·708 | 69·17 | 16·34 | 15·60 | 4·43 | 19·25 | 138·0 | 0·30 | 0·30 |
| 11 | ... | ... | ... | 13·6 | 13·1 | ... | 16·1 | ... | 3·45 | 4·15 |
| 12 | ... | ... | ... | ... | ... | ... | ... | ... | 24·00 | 28·15 |
| 13 | 95·8 | ·669 | 64·09 | 11·2 | 10·7 | ... | 13·2 | 143·2 | 24·00 | 52·15 |
| 14 | 97·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 76·15 |
| 15 | 96·5 | ·674 | 65·04 | 12·0 | 11·5 | ... | 14·1 | 143·2 | 24·00 | 100·15 |
| 16 | 97·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 124·15 |
| 17 | 96·9 | ·681 | 65·99 | 10·9 | 10·5 | ... | 12·9 | 142·3 | 24·00 | 148·15 |
| 18 | 97·5 | ·682 | 66·50 | 13·0 | 12·5 | ... | 15·4 | 143·0 | 24·00 | 172·15 |
| 19 | 97·7 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 196·15 |
| 20 | 97·4 | ·682 | 66·43 | 12·2 | 11·7 | ... | 14·4 | 142·8 | 20·45 | 217·00 |
| 21 | 97·7 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 241·00 |
| 22 | 96·9 | ·678 | 65·70 | 11·3 | 10·8 | ... | 13·3 | 142·9 | 24·00 | 265·00 |
| 23 | 96·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 289·00 |
| 24 | 96·9 | ·671 | 65·02 | 10·0 | 9·6 | ... | 11·8 | 144·4 | 24·00 | 313·00 |
| *25 | 97·0 | ·676 | 65·57 | 9·5 | 9·1 | ... | 11·2 | 143·5 | 24·00 | 337·00 |
| 26 | 96·8 | ... | ... | ... | ... | ... | ... | ... | 21·00 | 358·00 |
| *27 | 97·0 | ·677 | 65·66 | 9·6 | 9·2 | ... | 11·3 | 143·3 | 24·00 | 382·00 |
| *28 | 96·8 | ·671 | 64·95 | 8·4 | 8·1 | ... | 10·0 | 144·3 | 24·00 | 406·00 |
| *29 | 97·0 | ·671 | 65·08 | 8.7 | 8·4 | ... | 10·3 | 144·6 | 24·00 | 430·00 |
| 30 | 97·1 | ·673 | 65·31 | 10·9 | 10·5 | ... | 12·9 | 144·3 | 24·00 | 454·00 |
| May. | | | | | | | | | | |
| 1 | 96·8 | ·670 | 64·85 | 10·8 | 10·4 | ... | 12·8 | 144·5 | 24·00 | 478·00 |
| 2 | 96·7 | ·669 | 64·69 | 10·5 | 10·1 | ... | 12·4 | 144·5 | 24·00 | 502·00 |
| 3 | 96·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 526·00 |
| 4 | 97·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 550·00 |
| 5 | 96·9 | ·674 | 65·31 | 11·1 | 10·7 | ... | 13·2 | 143·8 | 24·00 | 574·00 |
| 6 | 97·0 | ·669 | 64·89 | 10·0 | 9·6 | ... | 11·8 | 145·0 | 23·30 | 597·30 |
| 7 | 96·8 | ·670 | 64·85 | 10·8 | 10·4 | ... | 12·8 | 144·5 | 24·00 | 621·30 |
| 8 | 96·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 645·30 |
| 9 | 97·0 | ·671 | 65·08 | 11·0 | 10·6 | ... | 13·0 | 144·6 | 24·00 | 669·30 |
| 10 | 97·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 693·30 |
| 11 | 96·8 | ·671 | 64·95 | 10·3 | 9·9 | ... | 12·2 | 144·3 | 24·00 | 717·30 |
| 12 | 95·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 741·30 |
| 13 | 97·4 | ... | ... | ... | ... | ... | ... | ... | 23·30 | 765·00 |
| 14 | 97·2 | ·673 | 65·41 | 9·9 | 9·5 | ... | 11·7 | 144·4 | 24·00 | 789·00 |
| 15 | 97·3 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 813·00 |
| 16 | 97·0 | ·671 | 65·08 | 10·3 | 9·9 | ... | 12·2 | 144·6 | 24·00 | 837·00 |
| 17 | 97·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 861·00 |
| 18 | 97·0 | ·668 | 64·79 | 10·4 | 10·0 | ... | 12·3 | 145·2 | 24·00 | 885·00 |
| 19 | 97·1 | ·669 | 64·96 | 8·7 | 8·4 | ... | 10·3 | 145·1 | 24·00 | 909·00 |
| 20 | 97·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 933·00 |
| 21 | 97·0 | ·666 | 64·60 | 10·1 | 9·7 | ... | 11·9 | 145·6 | 24·00 | 957·00 |
| 22 | 97·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 981·00 |
| 23 | 97·3 | ·664 | 64·60 | 9·5 | 9·1 | ... | 11·2 | 146·5 | 24·00 | 1,005·00 |
| 24 | 97·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 1,029·00 |
| *25 | 97·0 | ·668 | 64·79 | 7·4 | 7·1 | ... | 8·7 | 145·2 | 24·00 | 1,053·00 |
| 26 | ... | ... | ... | ... | ... | ... | ... | ... | 11·30 | 1,064·30 |
| 28 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

Resistance Cold, 256. Discoloration, 2½.

## *Edison Lamp, No. 19, 99 Volts.*

(Reduction Factor, 0·99. Resistance Cold, 250.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles, Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 99·7 | ·714 | 71·19 | 16·15 | 16·02 | 4·44 | 19·50 | 139·6 | 0·45 | 0·45 |
| 11 | ...... | ...... | ...... | 10·4 | 10·3 | ...... | 12·6 | ...... | 3·45 | 4·30 |
| 12 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 28·30 |
| 13 | 97·8 | ·681 | 66·60 | 11·9 | 11·8 | ...... | 14·4 | 143·6 | 24·00 | 52·30 |
| 14 | 99·0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 76·30 |
| 15 | 98·5 | ·683 | 67·28 | 12·4 | 12·3 | ...... | 15·0 | 144·2 | 24·00 | 100·30 |
| 16 | 99·1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 124·30 |
| 17 | 99·0 | ·688 | 68·11 | 11·8 | 11·7 | ...... | 14·3 | 143·9 | 24·00 | 148·30 |
| 18 | 99·5 | ·692 | 68·86 | 12.9 | 12·8 | ...... | 15·6 | 143·8 | 24·00 | 172·30 |
| 19 | 99·8 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 196·30 |
| 20 | 97·8 | ·670 | 65·53 | 11·0 | 10·9 | ...... | 13·3 | 146·0 | 20·45 | 217·15 |
| 21 | 100·0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 241·15 |
| 22 | 99·9 | ·681 | 67·35 | 11·5 | 11·4 | ...... | 13·9 | 145·2 | 24·00 | 265·15 |
| 23 | 99·1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 289·15 |
| 24 | 99·0 | ·679 | 67·22 | 9·9 | 9·8 | ...... | 12·0 | 145·8 | 24·00 | 313·15 |
| *25 | 99·4 | ·680 | 67·59 | 10·1 | 10·0 | ...... | 12·2 | 146·2 | 24·00 | 337·15 |
| 26 | 99·2 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 21·00 | 358·15 |
| *27 | 99·0 | ·679 | 67·22 | 9·2 | 9·1 | ...... | 11·1 | 145·8 | 24·00 | 382·15 |
| *28 | 99·0 | ·674 | 66·72 | 8·7 | 8·6 | ...... | 10·5 | 146·9 | 24·00 | 406·15 |
| *29 | 99·2 | ·678 | 67·25 | 8·8 | 8·7 | ...... | 10·6 | 146·3 | 24·00 | 430·15 |
| 30 | 99·2 | ·676 | 67·06 | 10·9 | 10·8 | ...... | 13·2 | 146·7 | 24·00 | 454·15 |
| May. | | | | | | | | | | |
| 1 | 99·0 | ·673 | 66·62 | 11·3 | 11·2 | ...... | 13·7 | 147·1 | 24·00 | 478·15 |
| 2 | 99·0 | ·674 | 66·72 | 11·2 | 11·1 | ...... | 13·5 | 146·9 | 24·00 | 502·15 |
| 3 | 99·0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 526·15 |
| 4 | 99·4 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 550·15 |
| 5 | 99·3 | ·667 | 66·23 | 11·6 | 11·5 | ...... | 14·0 | 148·9 | 24·00 | 574·15 |
| 6 | 99·3 | ·671 | 66·63 | 10·2 | 10·1 | ...... | 12·3 | 148·0 | 23·30 | 597·45 |
| 7 | 99·1 | ·669 | 66·29 | 10·5 | 10·4 | ...... | 12·7 | 148·1 | 24·00 | 621·45 |
| 8 | 99·2 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 645·45 |
| 9 | 99·1 | ·670 | 66·40 | 11·0 | 10·9 | ...... | 13·3 | 147·9 | 24·00 | 669·45 |
| 10 | 99·2 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 693·45 |
| 11 | 99·0 | 666 | 65·93 | 10·1 | 10·0 | ...... | 12·2 | 148·7 | 24·00 | 717·45 |
| 12 | 99·0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 741·45 |
| 13 | 99·6 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 23·30 | 765·15 |
| 14 | 99·2 | ·667 | 66·16 | 9·8 | 9·7 | ...... | 11·8 | 148·7 | 24·00 | 789·15 |
| 15 | 99·3 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 813·15 |
| 16 | 99·0 | ·668 | 66·13 | 10·3 | 10·2 | ...... | 12·4 | 148·2 | 24·00 | 837·15 |
| 17 | 99·1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 861·15 |
| 18 | 99·1 | ·666 | 66·00 | 10·3 | 10·2 | ...... | 12·4 | 148·8 | 24·00 | 885·15 |
| 19 | 99·1 | ·665 | 65·90 | 8·6 | 8·5 | ...... | 10·4 | 149·0 | 24·00 | 909·15 |
| 20 | 99·1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 933·15 |
| 21 | 99·4 | ·664 | 66·00 | 10·1 | 10·0 | ...... | 12·2 | 149·7 | 24·00 | 957·15 |
| 22 | 99·3 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 981·15 |
| 23 | 99·1 | ·661 | 65·50 | 9·7 | 9·6 | ...... | 11·7 | 149·9 | 24·00 | 1,005·15 |
| 24 | 99·1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 1,029·15 |
| *25 | 99·0 | ·662 | 65·53 | 7·4 | 7·3 | ...... | 8·9 | 149·5 | 24·00 | 1,053·15 |
| 26 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 11·30 | 1,064·45 |
| 28 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |

Resistance Cold, 267. Discoloration, 2½.

## *Edison Lamp, No. 20, 100 Volts.*

(Reduction Factor, 0·97. Resistance Cold, 256.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 100·7 | ·696 | 70·09 | 16·23 | 15·82 | 4·43 | 19·56 | 144·7 | 0·30 | 0·30 |
| 11 | ........ | ........ | ........ | 15·5 | 15·0 | ........ | 18·6 | ........ | 3·45 | 4·15 |
| 12 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 28·15 |
| 13 | 98·6 | ·669 | 65·96 | 12·3 | 12·0 | ........ | 14·9 | 147·4 | 24·00 | 52·15 |
| 14 | 100·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 76·15 |
| 15 | 99·5 | ·669 | 66·57 | 13·0 | 12·6 | ........ | 15·6 | 148·7 | 24·00 | 100·15 |
| 16 | 100·4 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 124·15 |
| 17 | 99·7 | ·674 | 67·20 | 12·5 | 12·2 | ........ | 15·1 | 147·9 | 24·00 | 148·15 |
| 18 | 100·4 | ·677 | 67·97 | 13·9 | 13·5 | ........ | 16·7 | 148·3 | 24·00 | 172·15 |
| 19 | 100·4 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 196·15 |
| 20 | 98·5 | ·666 | 65·60 | 11·4 | 11·1 | ........ | 13·8 | 147·9 | 20·45 | 217·00 |
| 21 | 100·6 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 241·00 |
| 22 | 100·0 | ·673 | 67·30 | 12·2 | 11·8 | ........ | 14·6 | 148·6 | 24·00 | 265·00 |
| 23 | 100·5 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 289·00 |
| 24 | 100·2 | ·655 | 65·63 | 9·7 | 9·4 | ........ | 11·7 | 153·0 | 24·00 | 313·00 |
| *25 | 100·6 | ·659 | 66·29 | 9·4 | 9·1 | ........ | 11·3 | 152·7 | 24·00 | 337·00 |
| 26 | 100·7 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 21·00 | 358·00 |
| *27 | 100·3 | ·662 | 66·39 | 9·6 | 9·3 | ........ | 11·5 | 151·5 | 24·00 | 382·00 |
| *28 | 100·2 | ·653 | 65·43 | 8·7 | 8·4 | ........ | 10·4 | 153·4 | 24·00 | 406·00 |
| *29 | 100·1 | ·651 | 65·16 | 8·5 | 8·2 | ........ | 10·2 | 153·8 | 24·00 | 430·00 |
| 30 | 100·2 | ·654 | 65·53 | 10·6 | 10·3 | ........ | 12·8 | 153·2 | 24·00 | 454·00 |
| May. | | | | | | | | | | |
| 1 | 100·1 | ·645 | 64·56 | 10·6 | 10·3 | ........ | 12·8 | 155·2 | 24·00 | 478·00 |
| 2 | 99·9 | ·650 | 64·93 | 10·3 | 10·0 | ........ | 12·4 | 153·7 | 24·00 | 502·00 |
| 3 | 99·9 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 526·00 |
| 4 | 99·8 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 550·00 |
| 5 | 99·9 | ·650 | 64·93 | 10·9 | 10·6 | ........ | 13·1 | 153·7 | 24·00 | 574·00 |
| 6 | 99·9 | ·648 | 64·73 | 10·1 | 9·8 | ........ | 12·2 | 154·2 | 23·30 | 597·30 |
| 7 | 99·6 | ·641 | 63·84 | 10·0 | 9·7 | ........ | 12·0 | 155·4 | 24·00 | 621·30 |
| 8 | 99·8 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 645·30 |
| 9 | 99·7 | ·646 | 64·41 | 10·5 | 10·2 | ........ | 12·6 | 154·3 | 24·00 | 669·30 |
| 10 | 100·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 693·30 |
| 11 | 99·6 | ·647 | 64·44 | 10·1 | 9·8 | ........ | 12·2 | 153·9 | 24·00 | 717·30 |
| 12 | 100·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 741·30 |
| 13 | 100·2 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 23·30 | 765·00 |
| 14 | 99·8 | ·643 | 64·17 | 9·5 | 9·2 | ........ | 11·4 | 155·2 | 24·00 | 789·00 |
| 15 | 99·9 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 813·00 |
| 16 | 99·7 | ·642 | 64·00 | 9·8 | 9·5 | ........ | 11·8 | 155·3 | 24·00 | 837·00 |
| 17 | 100·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 861·00 |
| 18 | 100·0 | ·639 | 63·90 | 9·9 | 9·6 | ........ | 11·9 | 156·5 | 24·00 | 885·00 |
| 19 | 99·5 | ·646 | 64·27 | 8·7 | 8·4 | ........ | 10·4 | 154·0 | 24·00 | 909·00 |
| 20 | 99·7 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 933·00 |
| 21 | 99·8 | ·642 | 64·07 | 9·9 | 9·6 | ........ | 11·9 | 155·5 | 24·00 | 957·00 |
| 22 | 99·9 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 981·00 |
| 23 | 99·9 | ·636 | 63·53 | 9·2 | 8·9 | ........ | 11·0 | 157·1 | 24·00 | 1,005·00 |
| 24 | 99·7 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 1,029·00 |
| *25 | 100·0 | ·637 | 63·70 | 6·9 | 6·7 | ........ | 8·3 | 157·0 | 24·00 | 1,053·00 |
| 26 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 11·30 | 1,064·30 |
| 28 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ |

Resistance Cold, 270. Discoloration, 2.

## Stanley–Thompson Lamps, 44 Volts.

### *Stanley-Thompson Lamp, No. 1.*

(Reduction Factor, 0·82. Resistance Cold, 80·7)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 44·40 | 1·096 | 48·66 | 15·2 | 12·39 | 3·92 | 15·36 | 40·51 | 2·00 | 2·00 |
| 11 | ........... | ........... | ........... | 15·8 | 13·0 | ........... | 16·1 | ........... | 3·45 | 5·45 |
| 12 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 29·45 |
| 13 | 43·05 | 1·041 | 44·81 | 12·5 | 10·2 | ........... | 12·7 | 41·35 | 24·00 | 53·45 |
| 14 | 42·80 | 1·023 | 43·78 | 12·2 | 10·0 | ........... | 12·4 | 41·84 | 24·00 | 77·45 |
| 15 | 43·55 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 101·45 |
| 16 | 43·75 | 1·025 | 44·85 | 13·1 | 10·8 | ........... | 13·4 | 42·68 | 24·00 | 125·45 |
| 17 | 43·30 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 149·45 |
| 18 | 43·35 | 1·004 | 43·52 | 11·7 | 9·6 | ........... | 11·9 | 43·18 | 24·00 | 173·45 |
| 19 | 44·35 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 197·45 |
| 20 | 43·20 | ·972 | 41·99 | 9·9 | 8·1 | ........... | 10·0 | 44·44 | 20·45 | 218·30 |
| 21 | 44·15 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 242·30 |
| 22 | 43·55 | ·965 | 42·02 | 9·0 | 7·4 | ........... | 9·2 | 45·13 | 24·00 | 266·30 |
| 23 | 43·95 | ·964 | 42·36 | 8·0 | 6·6 | ........... | 8·2 | 45·59 | 24·00 | 290·30 |
| 24 | 44·25 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 18·15 | 308·45 |

Carbon broke at side of loop 6.10 P.M., April 24, 1885. Discoloration, 4½.

### *Stanley-Thompson Lamp, No. 2.*

(Reduction Factor, 0·79. Resistance Cold, 84.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 44·45 | 1·039 | 46·18 | 14·0 | 11·10 | 4·16 | 13·38 | 42·78 | 1·30 | 1·30 |
| 11 | ........... | ........... | ........... | 17·0 | 14·3 | ........... | 17·3 | ........... | 3·45 | 5·15 |
| 12 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 29·15 |
| 13 | 44·10 | 1·001 | 44·14 | 12·2 | 9·7 | ........... | 11·7 | 44·06 | 24·00 | 53·15 |
| 14 | 43·90 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 77·15 |
| 15 | 44·10 | ·980 | 43·22 | 13·1 | 10·4 | ........... | 12·6 | 45·00 | 24·00 | 101·15 |
| 16 | 45·50 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 125·15 |
| 17 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 17·45 | 143·00 |

Carbon broke at side of loop 5.45 P.M., April 17, 1885. Discoloration, 3½.

## *Stanley-Thompson Lamp, No. 3.*

(Reduction Factor, 0·81. Resistance Cold, 79·5.)

| Date | Volts. | Amperes. | Watts. | Candles. | | Watts per Spher. Cand. | Candles Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Observed. | Spherical. | | | | | |
| 1885. April. | 43·90 | 1·068 | 46·88 | 19·7 | 15·88 | 2·95 | 19·46 | 41·10 | 1·15 | 1·15 |
| 11 | ........ | ........ | ........ | 22·2 | 18·0 | ........ | 22·1 | ........ | 3·45 | 5·00 |
| 12 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 29·00 |
| 13 | 45·40 | 1·027 | 46·62 | 16·8 | 13·6 | ........ | 16·7 | 44·21 | 24·00 | 53·00 |
| 14 | 46·25 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 77·00 |
| 15 | 46·90 | ·980 | 45·96 | 13·9 | 11·3 | ........ | 13·9 | 47·86 | 24·00 | 101·00 |
| 16 | 48·85 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 125·00 |
| 17 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 11·30 | 136·30 |

Carbon broke at side of loop, 11.30 A.M., April 17, 1885. Discoloration, 4½.

## *Stanley-Thompson Lamp, No. 4.*

(Reduction Factor, 0·77. Resistance Cold, 79·2.)

| Date. | Volts. | Amperes. | Watts. | Candles. | | Watts per Spher. Cand. | Candles Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Observed. | Spherical. | | | | | |
| 1885. April. | 43·90 | 1·080 | 47·41 | 18·3 | 14·07 | 3·36 | 17·40 | 40·65 | 1·15 | 1·15 |
| 11 | ........ | ........ | ........ | 18·5 | 14·2 | ........ | 17·6 | ........ | 3·45 | 5·00 |
| 12 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 29·00 |
| 13 | 43·55 | 1·042 | 45·38 | 13·9 | 10·7 | ........ | 13·3 | 41·79 | 24·00 | 53·06 |
| 14 | 43·55 | 1·025 | 44·44 | 12·5 | 9·6 | ........ | 11·9 | 42·29 | 24·00 | 77·00 |
| 15 | 43·80 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 101·00 |
| 16 | 44·75 | 1·038 | 46·45 | 15·0 | 11·6 | ........ | 14·4 | 43·11 | 24·00 | 125·00 |
| 17 | 43·70 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 149·00 |
| 18 | 44·55 | 1·000 | 44·55 | 12·5 | 9·6 | ........ | 11·9 | 44·55 | 24·00 | 173·00 |
| 19 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 5·00 | 178·00 |

Carbon broke at middle of loop 5·00 A. M., April 19, 1885. Discoloration, 4

## *Stanley-Thompson Lamp, No. 6.*

(Reduction Factor, 0·79. Resistance Cold, 85.)

| Date. | Volts. | Amperes. | Watts. | Candles. | | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Observed. | Spherical. | | | | | |
| 1885. April. | 43·90 | 1·001 | 43·94 | 13·1 | 10·31 | 4·26 | 12·58 | 43·86 | 1·00 | 1·00 |
| 11 | ... | ... | ... | 16·2 | 12·8 | ... | 15·6 | ... | 3·45 | 4·45 |
| 12 | ... | ... | ... | ... | ... | ... | ... | ... | 24·00 | 28·45 |
| 13 | 43·20 | ·983 | 42·46 | 12·3 | 9·7 | ... | 11·8 | 43·95 | 24·00 | 52·45 |
| 14 | 43·00 | ·978 | 42·05 | 11·3 | 8·9 | ... | 10·9 | 43·97 | 24·00 | 76·45 |
| 15 | 43·50 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 100·45 |
| 16 | 44·10 | ·996 | 43·92 | 14·4 | 11·4 | ... | 13·9 | 44·28 | 24·00 | 124·45 |
| 17 | 43·70 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 148·45 |
| 18 | 44·10 | ·972 | 42·86 | 12·4 | 9·8 | ... | 12·0 | 45·37 | 24·00 | 172·45 |
| 19 | 44·90 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 196·45 |
| 20 | 43·55 | ·945 | 41·15 | 11·1 | 8·8 | ... | 10·7 | 46·09 | 20·45 | 217·30 |
| 21 | 44·25 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 241·30 |
| 22 | 43·90 | ·939 | 41·22 | 10·1 | 8·0 | ... | 9·8 | 46·75 | 24·00 | 265·30 |
| 23 | 44·20 | ·939 | 41·50 | 8·7 | 6·9 | ... | 8·4 | 47·07 | 22·45 | 288·15 |

Carbon broke at side of loop 10.45 P.M., April 23, 1885. Discoloration, 3½.

## *Stanley-Thompson Lamp, No. 7.*

(Reduction Factor, 0·80. Resistance Cold, 78.)

| Date. | Volts. | Amperes. | Watts. | Candles. | | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Observed. | Spherical. | | | | | |
| 1885. April. | 43·90 | 1·078 | 47·32 | 15·5 | 12·46 | 3·79 | 15·15 | 40·72 | 1·15 | 1·15 |
| 11 | ... | ... | ... | 21·5 | 17·2 | ... | 21·0 | ... | 3·45 | 5·00 |
| 12 | ... | ... | ... | ... | ... | ... | ... | ... | 24·00 | 29·00 |
| 13 | 41·65 | 1·030 | 42·90 | 13·2 | 10·5 | ... | 12·8 | 40·44 | 24·00 | 53·00 |
| 14 | 41·00 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 77·00 |
| 15 | 40·40 | ·981 | 39·63 | 11·0 | 8·8 | ... | 10·7 | 41·18 | 24·00 | 101·00 |
| 16 | 41·00 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 125·00 |
| 17 | 43·00 | ... | ... | ... | ... | ... | ... | ... | 23·00 | 148·00 |
| 18 | 43.30 | 1·043 | 45·16 | 15·4 | 12·3 | ... | 15·0 | 41·52 | 24·00 | 172·00 |
| 19 | 43·40 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 196·00 |
| 20 | 42·40 | ·998 | 42·31 | 12·0 | 9·6 | ... | 11·7 | 42·49 | 20·45 | 216·45 |
| 21 | 42·95 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 240·45 |
| 22 | 45·15 | ·993 | 42·84 | 11·6 | 9·3 | ... | 11·3 | 43·45 | 24·00 | 264·45 |
| 23 | 43·35 | ·989 | 42·87 | 11·2 | 9·0 | ... | 11·0 | 43·83 | 18·45 | 283·30 |
| 24 | 43·30 | ... | ... | ... | ... | ... | ... | ... | 19·30 | 303·00 |

Carbon broke at middle of loop 7.35 P.M., April 24, 1885. Discoloration, 4.

## *Stanley-Thompson Lamp, No. 8.*

(Reduction Factor, 0·87. Resistance Cold, 79·8.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 43·90 | 1·044 | 45·83 | 12·1 | 10·58 | 4·33 | 12·92 | 42·05 | 1·15 | 1·15 |
| 11 | ..... | ..... | ..... | 14·2 | 12·4 | ..... | 15·1 | ..... | 3·45 | 5·00 |
| 12 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 24·00 | 29·00 |
| 13 | 42·30 | ·998 | 42·21 | 10·4 | 9·1 | ..... | 11·1 | 42·39 | 24·00 | 53·00 |
| 14 | 42·10 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 24·00 | 77·00 |
| 15 | 41·70 | ·977 | 40·74 | 10·3 | 9·0 | ..... | 11·0 | 42·68 | 24·00 | 101·00 |
| 16 | 42·60 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 24·00 | 125·00 |
| 17 | 43·10 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 24·00 | 149·00 |
| 18 | 43·10 | 1·013 | 43·66 | 12·7 | 11·0 | ..... | 13·4 | 42·55 | 24·00 | 173·00 |
| 19 | 43·05 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 24·00 | 197·00 |
| 20 | 42·15 | ·982 | 41·39 | 10·6 | 9·2 | ..... | 11·2 | 42·92 | 20·45 | 217·45 |
| 21 | 41·85 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 24·00 | 241·45 |
| 22 | 42·50 | ·987 | 41·94 | 10·8 | 9·4 | ..... | 11·5 | 43·06 | 24·00 | 265·45 |
| 23 | 43·70 | 1·018 | 44·48 | 11·2 | 9·7 | ..... | 11·8 | 42·93 | 17·00 | 282·45 |
| 24 | 43·35 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 12·45 | 295·30 |
| *25 | 43·95 | 1·001 | 43·99 | 10·5 | 9·1 | ..... | 11·1 | 43·91 | 24·00 | 319·30 |
| 26 | 43·70 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 21·00 | 340·30 |
| *27 | 43·85 | 1·001 | 43·89 | 10·8 | 9·4 | ..... | 11·5 | 43·81 | 24·00 | 364·30 |
| *28 | 44·25 | 1·002 | 44·33 | 9·3 | 8·1 | ..... | 9·9 | 44·16 | 24·00 | 388·30 |
| *29 | 44·10 | ·992 | 43·74 | 9·2 | 8·0 | ..... | 9·8 | 44·46 | 24·00 | 412·30 |
| 30 | 44·25 | ·990 | 43·80 | 11·9 | 10·4 | ..... | 12·7 | 44·70 | 24·00 | 436·30 |
| May. | | | | | | | | | | |
| 1 | 44·25 | ·980 | 43·36 | 10·5 | 9·1 | ..... | 11·1 | 45·15 | 24·00 | 460·30 |
| 2 | 44·15 | ·970 | 42·82 | 9·7 | 8·4 | ..... | 10·2 | 45·52 | 24·00 | 484·30 |
| 3 | 44·00 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 24·00 | 508·30 |
| 4 | 44·35 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 24·00 | 532·30 |
| 5 | 44·30 | ·964 | 42·70 | 10·0 | 8·7 | ..... | 10·6 | 45·95 | 24·00 | 556·30 |
| 6 | 43·65 | ·941 | 41·07 | 8·1 | 7·0 | ..... | 8·5 | 46·39 | 23·30 | 580·00 |
| 7 | 43·80 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 24·00 | 604·00 |
| 8 | 43·80 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 24·00 | 628·00 |
| 9 | 43·70 | ·936 | 40·90 | 8·7 | 7·6 | ..... | 9·3 | 46·69 | 24·00 | 652·00 |
| 10 | 44·05 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 24·00 | 676·00 |
| 11 | 44·05 | ·937 | 41·27 | 8·1 | 7·0 | ..... | 8·5 | 47·01 | 24·00 | 700·00 |
| 12 | 43·95 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 24·00 | 724·00 |
| 13 | 43·90 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 23·30 | 747·30 |
| 14 | 44·20 | ·935 | 41·32 | 8·4 | 7·3 | ..... | 8·9 | 47·27 | 24·00 | 771·30 |
| 15 | 44·25 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 24·00 | 795·30 |
| 16 | 44·20 | ·935 | 41·32 | 8·5 | 7·4 | ..... | 9·0 | 47·27 | 24·00 | 819·30 |
| 17 | 44·45 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 24·00 | 843·30 |
| 18 | 44·05 | ·927 | 40·83 | 8·5 | 7·4 | ..... | 9·0 | 47·52 | 24·00 | 867·30 |
| 19 | 44·15 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 24·00 | 891·30 |
| 20 | 44·05 | ·924 | 40·70 | 8·0 | 7·0 | ..... | 8·5 | 47·67 | 24·00 | 915·30 |
| 21 | 43·95 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 24·00 | 939·30 |
| 22 | 43·85 | ·896 | 39·29 | 7·2 | 6·3 | ..... | 7·7 | 48·94 | 24·00 | 963·30 |
| 23 | 43·95 | ·897 | 39·42 | 6·2 | 5·4 | ..... | 6·6 | 49·00 | 24·00 | 987·30 |
| 24 | 44·00 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 24·00 | 1,011·30 |
| *25 | 44·15 | ·896 | 39·55 | 5·1 | 4·4 | ..... | 5·4 | 49·27 | 24·00 | 1,035·30 |
| 26 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 11·30 | 1,047·00 |
| 28 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |

Resistance Cold, 92·0. Discoloration, 4.

## *Stanley-Thompson Lamp, No. 9.*

(Reduction Factor, 0·80. Resistance Cold, 83.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 43·80 | 1·036 | 45.37 | 20·4 | 16·29 | 2·78 | 19·59 | 42·28 | 1·00 | 1·00 |
| 11 | ........ | ........ | ........ | 22·4 | 17·9 | ........ | 21·5 | ........ | 3·45 | 4·45 |
| 12 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 28·45 |
| 13 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 11·00 | 39·45 |

Carbon broke at side of loop near shank 11.00 A. M., April 13, 1885. Discoloration, 2½.

## *Stanley-Thompson Lamp, No. 10.*

(Reduction Factor, 0·83. Resistance Cold, 82·4.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 43·75 | 1·031 | 45·10 | 19·3 | 15·94 | 2·83 | 19·29 | 42·43 | 1·00 | 1·00 |
| 11 | ........ | ........ | ........ | 19·5 | 16·2 | ........ | 19·6 | ........ | 3·45 | 4·45 |
| 12 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 28·45 |
| 13 | 42·40 | ·973 | 41·26 | 13·6 | 11·3 | ........ | 13·7 | 43·58 | 22·15 | 51·00 |
| 14 | 42·25 | ·951 | 40·18 | 13·4 | 11·1 | ........ | 13·4 | 44·43 | 21·00 | 75·00 |
| 15 | 43·20 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 99·00 |
| 16 | 43·15 | ·941 | 40·60 | 14·4 | 12·0 | ........ | 14·5 | 45·86 | 23·00 | 122·00 |
| 17 | 42·35 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 11·30 | 133·30 |
| 18 | 44·40 | ·956 | 42·44 | 15·7 | 13·0 | ........ | 15·7 | 46·44 | 24·00 | 157·30 |
| 19 | 44·10 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 181·30 |
| 20 | 43·55 | ·896 | 39·02 | 11·3 | 9·4 | ........ | 11·4 | 48·60 | 20·45 | 202·15 |
| 21 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 4·00 | 206·15 |

Carbon broke at middle of loop 4.00 A. M., April 21, 1885. Discoloration, 3½.

## *Stanley-Thompson Lamp, No. 11.*

(Reduction Factor, 0·80. Resistance Cold, 79·0.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles, Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 43·90 | 1·059 | 46·49 | 19·1 | 15·19 | 3·06 | 19·28 | 41·45 | 1·00 | 1·00 |
| 11 | ... | ... | ... | 21·2 | 19·4 | ... | 21·6 | ... | 3·45 | 4·45 |
| 12 | ... | ... | ... | ... | ... | ... | ... | ... | 24·00 | 28·45 |
| 13 | 44·10 | 1·051 | 46·34 | 16·5 | 13·2 | ... | 16·8 | 41·96 | 24·00 | 52·45 |
| 14 | 44·75 | 1·036 | 46·36 | 15·5 | 12·4 | ... | 15·7 | 43·20 | 24·00 | 76·45 |
| 15 | 45·10 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 100·45 |
| 16 | 44·25 | ·975 | 43·15 | 12·8 | 10·2 | ... | 13·0 | 45·39 | 24·00 | 124·45 |
| 17 | 44·10 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 148·45 |
| 18 | 44·65 | ·954 | 42·59 | 10·4 | 8·3 | ... | 10·5 | 46·80 | 24·00 | 172·45 |
| 19 | 43·95 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 196·45 |
| 20 | 42·75 | ·899 | 38·43 | 7·8 | 6·2 | ... | 7·9 | 47·55 | 20·45 | 217·30 |
| 21 | 43·60 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 241·30 |
| 22 | 43·50 | ·901 | 39·19 | 7·4 | 5·9 | ... | 7·5 | 48·28 | 24·00 | 265·30 |
| 23 | ... | ... | ... | ... | ... | ... | ... | ... | 9·30 | 275·00 |

Carbon broke at loop 9.30 A. M., April 23, 1885. Discoloration, 4½.

## *Stanley-Thompson Lamp, No. 12.*

(Reduction Factor, ·80, not determined.)

| Date | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles, Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | | | | | | | | | | |
| 19 | 43·30 | ·887 | 38·41 | 9·6 | ... | ... | ... | 48·82 | 9·00 | 9·00 |
| 20 | 43·25 | ·862 | 37·28 | 9·7 | ... | ... | ... | 50·17 | 20·45 | 29·45 |
| 21 | 44·10 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 53·45 |
| 22 | 43·80 | ·860 | 37·66 | 9·5 | ... | ... | ... | 50·93 | 24·00 | 77·45 |
| 23 | 43·80 | ·858 | 37·58 | 8·2 | ... | ... | ... | 51·05 | 24·00 | 101·45 |
| 24 | 43·75 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 125·45 |
| *25 | 44·35 | ·857 | 38·00 | 8·2 | ... | ... | ... | 51·75 | 24·00 | 149·45 |
| 26 | 43·90 | ... | ... | ... | ... | ... | ... | ... | 21·00 | 170·45 |
| *27 | 43·90 | ·857 | 37·62 | 8·6 | ... | ... | ... | 51·23 | 24·00 | 194·45 |
| *28 | 44·25 | ·858 | 37·95 | 8·0 | ... | ... | ... | 51·57 | 24·00 | 218·45 |
| *29 | 44·35 | ·853 | 37·83 | 8·3 | ... | ... | ... | 51·99 | 24·00 | 242·45 |
| 30 | 43·95 | ·844 | 37·09 | 10·6 | ... | ... | ... | 52·07 | 24·00 | 266·45 |
| May. | | | | | | | | | | |
| 1 | 44·15 | ·841 | 37·13 | 9·7 | ... | ... | ... | 52·50 | 24·00 | 290·45 |
| 2 | 44·25 | ·841 | 37·21 | 9·7 | ... | ... | ... | 52·62 | 16·30 | 307·15 |

Carbon destroyed by too high potential 4.30 P. M., May 2, 1885. Discoloration, 6.

# Stanley–Thompson Lamps, 96 Volts.

## *Stanley-Thompson Lamp, No. 26.*

(Reduction Factor, 0·82. Resistance Cold, 330.)

| Date. | Volts. | Amperes. | Volts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Mean Horizontal Candles. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 96·4 | ·578 | 55·72 | 15·85 | 13·10 | 4·25 | 15·73 | 166·8 | 1·00 | 1·00 |
| 11 | ... | ... | ... | 18·5 | 15·2 | ... | 18·2 | ... | 3·45 | 4·45 |
| 12 | ... | ... | ... | ... | ... | ... | ... | ... | 24·00 | 28·45 |
| 13 | 95·1 | ·554 | 52·69 | 14·2 | 11·6 | ... | 13·9 | 171·7 | 24·00 | 52·45 |
| 14 | 96·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 76·45 |
| 15 | ... | ... | ... | ... | ... | ... | ... | ... | 1·30 | 78·15 |

Carbon broke at side of loop 1.30 A. M., April 15, 1885. Discoloration, 2.

## *Stanley-Thompson Lamp, No. 28.*

(Reduction Factor, 0·86. Resistance Cold, 328.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Mean Horizontal Candles. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 96·5 | ·584 | 56·35 | 19·80 | 17·11 | 3·29 | 19·78 | 165·2 | 1·45 | 1·45 |
| 11 | ... | ... | ... | 23·8 | 20·5 | ... | 23·8 | ... | 3·45 | 5·30 |
| 12 | ... | ... | ... | ... | ... | ... | ... | ... | 24·00 | 29·30 |
| 13 | 95·7 | ·562 | 53·78 | 17·2 | 14·8 | ... | 17·2 | 170·3 | 24·00 | 53·30 |
| 14 | 96·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 77·30 |
| 15 | 96·9 | ·541 | 52·43 | 15·5 | 13·3 | ... | 15·4 | 179·1 | 24·00 | 101·30 |
| 16 | 98·8 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 125·30 |
| 17 | 98·3 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 149·30 |
| 18 | 96·8 | ·519 | 50·24 | 12·2 | 10·5 | ... | 12·2 | 186·5 | 24·00 | 173·30 |
| 19 | 98·8 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 197·30 |
| 20 | 95·4 | ·497 | 47·41 | 10·2 | 8·8 | ... | 10·2 | 192·0 | 20·45 | 218·15 |
| 21 | ... | ... | ... | ... | ... | ... | ... | ... | 14·45 | 233·00 |

Carbon broke at side of loop 2. 45 P. M., April 21, 1885. Discoloration, 3.

## *Stanley-Thompson Lamp, No. 29.*

(Reduction Factor, 0·83. Resistance Cold, 368.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Mean Horizontal Candles. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 96·4 | ·537 | 51·76 | 19·82 | 16·49 | 3·14 | 19·48 | 179·5 | 0·45 | 0·45 |
| 11 | ... | ... | ... | 21·8 | 18·1 | ... | 21·4 | ... | 3·45 | 4·30 |
| 12 | ... | ... | ... | ... | ... | ... | ... | ... | 24·00 | 28·30 |
| 13 | 95·0 | ·491 | 46·64 | 14·9 | 12·4 | ... | 14·6 | 193·5 | 24·00 | 52·30 |
| 14 | 96·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 76·30 |
| 15 | 96·3 | ·482 | 46·41 | 14·9 | 12·4 | ... | 14·6 | 199·8 | 24·00 | 100·30 |
| 16 | 98·4 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 124·30 |
| 17 | 96·6 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 148·30 |
| 18 | 95·9 | ·459 | 44·01 | 12·1 | 10·0 | ... | 11·8 | 208·9 | 24·00 | 172·30 |
| 19 | ... | ... | ... | ... | ... | ... | ... | ... | 3·30 | 176·00 |

Carbon broke at side of loop 3.30 A. M., April 19, 1885. Discoloration, 3½.

## *Stanley-Thompson Lamp, No. 33.*

(Reduction Factor, 0·82. Resistance Cold, 365.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Mean Horizontal Candles. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 96·4 | ·528 | 50·90 | 17·45 | 14·32 | 3·55 | 17·17 | 182·6 | 0·30 | 0·30 |
| 11 | ... | ... | ... | 19·2 | 15·7 | ... | 18·8 | ... | 3·45 | 4·15 |
| 12 | ... | ... | ... | ... | ... | ... | ... | ... | 24·00 | 28·15 |
| 13 | 95·0 | ·487 | 46·27 | 11·6 | 9·5 | ... | 11·4 | 195·1 | 24·00 | 52·15 |
| 14 | 96·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 76·15 |
| 15 | 96·0 | ·484 | 46·46 | 12·3 | 10·1 | ... | 12·1 | 198·3 | 24·00 | 100·15 |
| 16 | 98·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 124·15 |
| 17 | 96·5 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 148·15 |
| 18 | 95·8 | ·472 | 45·22 | 11·4 | 9·3 | ... | 11·2 | 203·0 | 24·00 | 172·15 |
| 19 | 96·7 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 196·15 |
| 20 | 95·0 | ·463 | 43·98 | 10·0 | 8·2 | ... | 9·8 | 205·2 | 20·45 | 217·00 |
| 21 | 96·5 | ·471 | 45·45 | 10·5 | 8·6 | ... | 10·3 | 204·9 | 24·00 | 241·00 |
| 22 | 96·6 | ... | ... | ... | ... | ... | ... | ... | 15·30 | 256·30 |

Carbon broke at side of loop—3.30 P. M., April 22, 1885. Discoloration, 2.

## *Stanley-Thompson Lamp, No. 30.*

(Reduction Factor, 0·84. Resistance Cold, 339.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Mean Horizontal Candles. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 96·3 | ·544 | 53·35 | 15·35 | 12·94 | 4·12 | 15·65 | 173·8 | 0·45 | 0·45 |
| 11 | ... | ... | ... | 15·8 | 13·3 | ... | 16·1 | ... | 3·45 | 4·30 |
| 12 | ... | ... | ... | ... | ... | ... | ... | ... | 24·00 | 28·30 |
| 13 | 94·9 | ·499 | 47·36 | 9·8 | 8·2 | ... | 9·9 | 190·2 | 24·00 | 52·30 |
| 14 | 95·8 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 76·30 |
| 15 | 95·4 | ·504 | 48·08 | 11·3 | 9·5 | ... | 11·5 | 189·3 | 24·00 | 100·30 |
| 16 | 97·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 124·30 |
| 17 | 95·7 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 148·30 |
| 18 | 95·6 | ·506 | 48·37 | 11·9 | 10·0 | ... | 12·1 | 188·9 | 24·00 | 172·30 |
| 19 | 96·3 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 196·30 |
| 20 | 94·6 | ·499 | 47·20 | 10·4 | 8·7 | ... | 10·5 | 189·6 | 20·45 | 217·15 |
| 21 | 96·1 | ·505 | 48·53 | 10·8 | 9·1 | ... | 11·0 | 190·3 | 24·00 | 241·15 |
| 22 | 96·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 265·15 |
| 23 | 96·6 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 289·15 |
| 24 | 96·2 | ·498 | 47·90 | 9·5 | 8·0 | ... | 9·7 | 193·2 | 24·00 | 313·15 |
| *25 | 96·5 | ·498 | 48·05 | 9·2 | 7·7 | ... | 9·3 | 193·8 | 24·00 | 337·15 |
| 26 | 96·2 | ... | ... | ... | ... | ... | ... | ... | 21·00 | 358·15 |
| *27 | 96·1 | ·492 | 47·28 | 8·8 | 7·4 | ... | 9·0 | 195·3 | 24·00 | 382·15 |
| *28 | 96·1 | ·492 | 47·28 | 7·6 | 6·4 | ... | 7·7 | 195·3 | 24·00 | 406·15 |
| *29 | 96·5 | ·492 | 47·47 | 7·9 | 6·6 | ... | 8·0 | 196·1 | 24·00 | 430·15 |
| 30 | 96·1 | ·489 | 46·99 | 10·5 | 8·8 | ... | 10·6 | 196·5 | 24·00 | 454·15 |
| May. | | | | | | | | | | |
| 1 | 96·4 | ·489 | 47·14 | 10·2 | 8·6 | ... | 10·4 | 197·1 | 24·00 | 478·15 |
| 2 | 96·4 | ·488 | 47·04 | 9·6 | 8·1 | ... | 9·8 | 197·5 | 24·00 | 502·15 |
| 3 | 96·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 526·15 |
| 4 | 96·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 550·15 |
| 5 | 95·9 | ·483 | 46·32 | 9·3 | 7·8 | ... | 9·4 | 198·6 | 24·00 | 574·15 |
| 6 | 96·0 | ·480 | 46·08 | 8·3 | 7·0 | ... | 8·5 | 200·0 | 23·30 | 597·45 |
| 7 | 96·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 621·45 |
| 8 | 96·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | ·645·45 |
| 9 | 95·8 | ·477 | 45·69 | 9·2 | 7·7 | ... | 9·3 | 200·8 | 24·00 | 669·45 |
| 10 | 96·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 693·45 |
| 11 | 96·0 | ·477 | 45·79 | 8·4 | 7·1 | ... | 8·6 | 201·3 | 24·00 | 717·45 |
| 12 | 95·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 741·45 |
| 13 | 95·5 | ... | ... | ... | ... | ... | ... | ... | 23·30 | 765·15 |
| 14 | 96·1 | ·475 | 45·64 | 8·1 | 6·8 | ... | 8·2 | 202·3 | 24·00 | 789·15 |
| 15 | 96 3 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 813·15 |
| 16 | 96·0 | ·476 | 45·69 | 8·5 | 7·1 | ... | 8·6 | 201·7 | 24·00 | 837·15 |
| 17 | 96·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 861·15 |
| 18 | 96·1 | ·472 | 45·35 | 8·5 | 7·1 | ... | 8·6 | 203·6 | 24·00 | 885·15 |
| 19 | 96·0 | ·473 | 45·40 | 7·1 | 6·0 | ... | 7·3 | 203·0 | 24·00 | 909·15 |
| 20 | 96·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 933·15 |
| 21 | 96·2 | ·469 | 45·11 | 8·3 | 7·0 | ... | 8·5 | 205·1 | 24·00 | 957·15 |
| 22 | 95·7 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 981·15 |
| 23 | 96·2 | ·470 | 45·21 | 7·5 | 6·3 | ... | 7·6 | 204·7 | 24·00 | 1,005·15 |
| 24 | 96·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 1,029·15 |
| *25 | 96·1 | ·470 | 45·17 | 6·1 | 5·1 | ... | 6·2 | 204·5 | 24·00 | 1,053·15 |
| 26 | ... | ... | ... | ... | ... | ... | ... | ... | 11·30 | 1,064·45 |
| 28 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

Resistance Cold, 389. Discoloration, 3.

## *Stanley-Thompson Lamp, No. 34.*

(Reduction Factor, 0·89. Resistance Cold, 349.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Mean Horizontal Candles. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. | 96·4 | ·558 | 53·79 | 17·05 | 14·17 | 3·79 | 16·95 | 172·8 | 0·45 | 0·45 |
| April. | | | | | | | | | | |
| 11 | | | | 19·4 | 17·3 | ........... | 20·6 | | 3·45 | 4·30 |
| 12 | | | | ........... | ........... | ........... | ........... | | 24·00 | 28·30 |
| 13 | 94·8 | ·534 | 50·62 | 13·3 | 11·9 | ........... | 14·0 | 177·5 | 24·00 | 52·30 |
| 14 | 96·0 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 76·30 |
| 15 | 95·5 | ·529 | 50·52 | 14·6 | 13·0 | ........... | 15·5 | 180·5 | 24·00 | 100·30 |
| 16 | 97·6 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 124·30 |
| 17 | 96·2 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 148·30 |
| 18 | 96·4 | ·527 | 50·80 | 14·3 | 12·7 | ........... | 15·1 | 182·9 | 24·00 | 172·30 |
| 19 | 97·3 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 196·30 |
| 20 | 94·5 | ·508 | 48·00 | 11·6 | 10·3 | ........... | 12·3 | 186·0 | 20·45 | 217·15 |
| 21 | 96·2 | ·518 | 49·83 | 12·4 | 11·0 | ........... | 13·1 | 185·7 | 24·00 | 241·15 |
| 22 | 96·2 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 265·15 |
| 23 | 96·4 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 289·15 |
| 24 | 96·5 | ·509 | 49·11 | 10·9 | 9·7 | ........... | 11·5 | 189·6 | 24·00 | 313·15 |
| *25 | 96·6 | ·510 | 49·26 | 10·7 | 9·5 | ........... | 11·3 | 189·4 | 24·00 | 337·15 |
| 26 | 96·0 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 21·00 | 358·15 |
| *27 | 96·1 | ·502 | 48·24 | 9·8 | 8·7 | ........... | 10·4 | 191·4 | 24·00 | 382·15 |
| *28 | 96·2 | ·493 | 47·42 | 8·0 | 7·1 | ........... | 8·4 | 195·1 | 24·00 | 406·15 |
| *29 | 96·3 | ·499 | 48·05 | 8·6 | 7·7 | ........... | 9·2 | 193·0 | 24·00 | 430·15 |
| 30 | 96·6 | ·501 | 48·39 | 11·6 | 10·3 | ........... | 12·3 | 192·8 | 24·00 | 454·15 |
| May. | | | | | | | | | | |
| 1 | 96·3 | ·493 | 47·47 | 11·3 | 10·1 | ........... | 12·0 | 195·3 | 24·00 | 478·15 |
| 2 | 96·5 | ·495 | 47·76 | 10·0 | 8·9 | ........... | 10·6 | 195·0 | 24·00 | 502·15 |
| 3 | 95·8 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 22·30 | 524·45 |

Carbon broke at side of loop 10.30 P. M., May 3, 1885. Discoloration, 3½.

## *Stanley-Thompson Lamp, No. 35.*

(Reduction Factor, 0·82. Resistance Cold, 350.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Mean Horizontal Candles. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 96·4 | ·552 | 53·21 | 16·38 | 13·72 | 3·87 | 16·59 | 174·6 | 0·45 | .. 0·45 |
| 11 | | | | 17·8 | 14·6 | ........ | 17·8 | ........ | 3·45 | 4·30 |
| 12 | | | | ........ | ........ | ........ | ........ | ........ | 24·00 | 28·30 |
| 13 | 95·2 | ·535 | 50·93 | 12·5 | 10·2 | ........ | 12·4 | 177·9 | 24·00 | 52·30 |
| 14 | 96·2 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 76·30 |
| 15 | 95·9 | ·524 | 50·25 | 12·7 | 10·4 | ........ | 12·7 | 183·0 | 23·00 | 99·30 |

Carbon broke at middle of loop 11.00 P. M., April 15, 1885. Discoloration, 2.

## *Stanley-Thompson Lamp, No. 36.*

(Reduction Factor, 0·83. Resistance Cold, 336.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Mean Horizontal Candles. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 96·2 | ·576 | 55·41 | 19·92 | 16·49 | 3·36 | 19·55 | 167·0 | 0·45 | 0·45 |
| 11 | ........ | ........ | ........ | 23·8 | 19·8 | ........ | 23·6 | ........ | 3·45 | 4·30 |
| 12 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 28·30 |
| 13 | 95·4 | ·545 | 52·00 | 14·4 | 12·0 | ........ | 14·3 | 175·0 | 24·00 | 52·30 |
| 14 | 96·2 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 76·30 |
| 15 | 95·8 | ·531 | 50·87 | 13·7 | 11·4 | ........ | 13·6 | 180·4 | 24·00 | 100·30 |
| 16 | 98·4 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 124·30 |
| 17 | 97·2 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 148·30 |
| 18 | 95·2 | ·505 | 48·07 | 10·9 | 9·0 | ........ | 10·7 | 188·5 | 24·00 | 172·30 |
| 19 | 95·8 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 196·30 |
| 20 | 94·0 | ·495 | 46·53 | 9·4 | 7·8 | ........ | 9·3 | 189·9 | 20·45 | 217·15 |
| 21 | 95·7 | ·497 | 47·56 | 9·9 | 8·2 | ........ | 9·8 | 192·6 | 24·00 | 241·15 |
| 22 | 95·9 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 265·15 |
| 23 | 96·1 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 289·15 |
| 24 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 11·30 | 300·45 |

Carbon broke at side of loop 11.30 A. M., April 24, 1885. Discoloration, 3½.

## *Stanley-Thompson Lamp, No. 37.*

Reduction Factor, 0·81. Resistance Cold, 350.

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Mean Horizontal Candles. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 97·2 | ·534 | 51·90 | 17·55 | 14·28 | 3·63 | 17·29 | 182·0 | 0·45 | 0·45 |
| 11 | .......... | .......... | .......... | 15·5 | 12·6 | .......... | 15·2 | .......... | 3·45 | 4·30 |
| 12 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 28·30 |
| 13 | 95·5 | ·494 | 47·18 | 12·5 | 10·1 | .......... | 12·2 | 193·3 | 24·00 | 52·30 |
| 14 | 95·7 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 76·30 |
| 15 | 95·0 | ·484 | 45·98 | 12·2 | 9·9 | .......... | 12·0 | 196·3 | 24·00 | 100·30 |
| 16 | 97·6 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 124·30 |
| 17 | 96·3 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 148·30 |
| 18 | 96·5 | ·481 | 46·41 | 12·0 | 9·7 | .......... | 11·7 | 200·6 | 24·00 | 172·30 |
| 19 | 97·1 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 196·30 |
| 20 | 95·9 | ·474 | 45·45 | 10·9 | 8·8 | .......... | 10·6 | 202·3 | 20·45 | 217·15 |
| 21 | 97·0 | ·480 | 46·56 | 10·2 | 8·3 | .......... | 10·0 | 202·1 | 24·00 | 241·15 |
| 22 | 96·9 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 265·15 |
| 23 | 96·3 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 289·15 |
| 24 | 96·2 | ·470 | 45·22 | 8·8 | 7·1 | .......... | 8·6 | 204·7 | 24·00 | 313·15 |
| *25 | 96·4 | ·466 | 44·92 | 8·1 | 6·6 | .......... | 8·0 | 206·9 | 24·00 | 337·15 |
| 26 | 96·0 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 21·00 | 358·15 |
| *27 | 95·9 | ·463 | 44·40 | 8·0 | 6·5 | .......... | 7·9 | 207·1 | 24·00 | 382·15 |
| *28 | 96·0 | ·461 | 44·25 | 7·2 | 5·8 | .......... | 7·0 | 208·2 | 24·00 | 406·15 |
| *29 | 96·2 | ·462 | 44·44 | 7·1 | 5·8 | .......... | 7·0 | 208·2 | 24·00 | 430·15 |
| 30 | 96·3 | ·461 | 44·39 | 9·5 | 7·7 | .......... | 9·3 | 208·9 | 24·00 | 454·15 |
| May. | | | | | | | | | | |
| 1 | 96·1 | ·460 | 44·20 | 9·4 | 7·6 | .......... | 9·2 | 208·9 | 24·00 | 478·15 |
| 2 | 96·3 | ·460 | 44·29 | 8·5 | 6·9 | .......... | 8·3 | 209·3 | 24·00 | 502·15 |
| 3 | 96·0 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 526·15 |
| 4 | 96·3 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 550·15 |
| 5 | 96·0 | ·456 | 43·77 | 8·9 | 7·2 | .......... | 8·7 | 210·5 | 24·00 | 574·15 |
| 6 | 96·0 | ·455 | 43·68 | 8·1 | 6·5 | .......... | 7·9 | 211·0 | 23·30 | 597·45 |
| 7 | 96·1 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 621·45 |
| 8 | 96·2 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 645·45 |
| 9 | 96·0 | ·450 | 43·20 | 8·6 | 7·0 | .......... | 8·5 | 213·3 | 24·00 | 669·45 |
| 10 | 96·3 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 693·45 |
| 11 | 96·3 | ·452 | 43·52 | 8·2 | 6·6 | .......... | 8·0 | 213·1 | 24·00 | 717·45 |
| 12 | 96·2 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 741·45 |
| 13 | 97·7 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 23·30 | 765·15 |
| 14 | 95·6 | ·447 | 42·73 | 7·9 | 6·4 | .......... | 7·7 | 213·9 | 24·00 | 789·15 |
| 15 | 95·9 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 813·15 |
| 16 | 95·5 | ·444 | 42·40 | 7·7 | 6·2 | .......... | 7·5 | 215·1 | 24·00 | 837·15 |
| 17 | 96·0 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 861·15 |
| 18 | 95·9 | ·445 | 42·67 | 8·3 | 6·7 | .......... | 8·1 | 215·5 | 20·15 | 881·30 |

Carbon broke at side of loop 8.15 P. M., May 18, 1885. Discoloration 2½.

## *Stanley-Thompson Lamp, No. 41.*

(Reduction Factor, 0·81. Resistance Cold, 340.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Mean. Horizontal Candles. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 97·2 | ·567 | 55·11 | 15·97 | 12·93 | 4·26 | 15·51 | 171·4 | 0·45 | 0·45 |
| 11 | ............ | ............ | ............ | 15·0 | 12·2 | ............ | 14·6 | ............ | 3·45 | 4·30 |
| 12 | ............ | ............ | ............ | ............ | ............ | ............ | ............ | ............ | 24·00 | 28·30 |
| 13 | 95·6 | ·526 | 50·29 | 13·6 | 11·0 | ............ | 13·2 | 181·8 | 24·00 | 52·30 |
| 14 | 96·3 | ·529 | 50·94 | 13·4 | 10·9 | ............ | 13·1 | 182·0 | 24·00 | 76·30 |
| 15 | 96·3 | ............ | ............ | ............ | ............ | ............ | ............ | ............ | 24·00 | 100·30 |
| 16 | 98·1 | ·531 | 52·09 | 16·7 | 13·5 | ............ | 16·2 | 184·7 | 24·00 | 124·30 |
| 17 | 97·5 | ·529 | 51·57 | 14·0 | 11·4 | ............ | 13·7 | 184·3 | 24·00 | 148·30 |
| 18 | 97·7 | ............ | ............ | ............ | ............ | ............ | ............ | ............ | 24·00 | 172·30 |
| 19 | 97·7 | ·519 | 50·70 | 12·1 | 9·8 | ............ | 11·8 | 188·2 | 24·00 | 196·30 |
| 20 | 98·3 | ............ | ............ | ............ | ............ | ............ | ............ | ............ | 20·45 | 217·15 |
| 21 | 97·0 | ·513 | 49·75 | 11·3 | 9·2 | ............ | 11·0 | 189·1 | 24·00 | 241·15 |
| 22 | 95·9 | ............ | ............ | ............ | ............ | ............ | ............ | ............ | 24·00 | 265·15 |
| 23 | 96·1 | ·501 | 48·15 | 9·3 | 7·5 | ............ | 9·0 | 191·8 | 24·00 | 289·15 |
| 24 | 95·9 | ............ | ............ | ............ | ............ | ............ | ............ | ............ | 24·00 | 313·15 |
| *25 | 95·9 | ·499 | 47·85 | 8·1 | 6·6 | ............ | 7·9 | 192·2 | 24·00 | 337·15 |
| 26 | 96·2 | ............ | ............ | ............ | ............ | ............ | ............ | ............ | 21·00 | 358·15 |
| *27 | 95·8 | ·492 | 47·13 | 9·1 | 7·4 | ............ | 8·9 | 194·7 | 24·00 | 382·15 |
| *28 | 96·1 | ·496 | 47·66 | 7·5 | 6·1 | ............ | 7·3 | 193·7 | 24·00 | 406·15 |
| *29 | 96·0 | ·495 | 47·52 | 7·9 | 6·4 | ............ | 7·7 | 193·9 | 24·00 | 430·15 |
| 30 | 95·9 | ·496 | 47·56 | 10·6 | 8·6 | ............ | 10·3 | 193·3 | 24·00 | 454·15 |
| May. | | | | | | | | | | |
| 1 | 96·1 | ·492 | 47·28 | 9·9 | 8·0 | ............ | 9·6 | 195·3 | 24·00 | 478·15 |
| 2 | 96·0 | ·492 | 47·23 | 9·5 | 7·7 | ............ | 9·2 | 195·1 | 24·00 | 502·15 |
| 3 | 96·1 | ............ | ............ | ............ | ............ | ............ | ............ | ............ | 24·00 | 526·15 |
| 4 | 96·3 | ............ | ............ | ............ | ............ | ............ | ............ | ............ | 24·00 | 550·15 |
| 5 | 96·2 | ·491 | 47·23 | 9·9 | 8·0 | ............ | 9·6 | 195·9 | 24·00 | 574·15 |
| 6 | 96·0 | ·488 | 46·84 | 9·4 | 7·6 | ............ | 9·1 | 196·7 | 23·30 | 597·45 |
| 7 | 96·3 | ............ | ............ | ............ | ............ | ............ | ............ | ............ | 24·00 | 621·45 |
| 8 | 96·3 | ............ | ............ | ............ | ............ | ............ | ............ | ............ | 24·00 | 645·45 |
| 9 | 96·1 | ·485 | 46·60 | 9·7 | 7·9 | ............ | 9·5 | 198·1 | 24·00 | 669·45 |
| 10 | ............ | ............ | ............ | ............ | ............ | ............ | ............ | ............ | 12·45 | 682·30 |

Carbon broke at side of loop 12.45 P.M., May 10, 1885. Discoloration, 2½.

## Woodhouse and Rawson Lamps, 55 Volts.

### *Woodhouse and Rawson Lamp, No. 1.*

(Reduction Factor, 1·07. Resistance Cold, 98.)

| Date. | Volts. | Amperes. | Watts. | Candles. | | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Observed. | Spherical. | | | | | |
| 1885. April. | 55·30 | 1·162 | 64·26 | 17·7 | 19·01 | 3·38 | 22·14 | 47·59 | 1·15 | 1·15 |
| 11 | ........... | ........... | ........... | 19·4 | 20·8 | ........... | 21·1 | ........... | 3·15 | 4·30 |
| 12 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 28·30 |
| 13 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 12·30 | 41·00 |

Carbon broke at middle of loop at 12.30 P.M., April 13, 1885. Discoloration, 3.

### *Woodhouse and Rawson Lamp, No. 3.*

(Reduction Factor, 1·14. Resistance Cold, 102.)

| Date | Volts. | Amperes. | Watts. | Candles. | | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Observed. | Spherical. | | | | | |
| 1885. April. | 55·2 | 1·162 | 64·14 | 17·6 | 20·06 | 3·19 | 24·39 | 47·50 | 0·45 | 0·45 |
| 11 | ........... | ........... | ........... | 26·4 | 30·1 | ........... | 36·7 | ........... | 3·15 | 4·00 |
| 12 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 28·00 |
| 13 | 55·35 | 1·184 | 65·53 | 19·6 | 22·3 | ........... | 27·2 | 46·75 | 23·45 | 51·45 |
| 14 | 56·70 | 1·179 | 66·85 | 18·5 | 21·1 | ........... | 25·7 | 48·09 | 24·00 | 75·45 |
| 15 | 56·40 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 99·45 |
| 16 | 55·90 | 1·120 | 62·60 | 16·3 | 18·6 | ........... | 22·7 | 49·91 | 24·00 | 123·45 |
| 17 | 56·50 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 147·45 |
| 18 | 53·50 | 1·016 | 55·96 | 11·0 | 12·5 | ........... | 15·3 | 51·15 | 24·00 | 171·45 |
| 19 | 56·30 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 195·45 |
| 20 | 54·20 | 1·025 | 55·55 | 10·5 | 12·0 | ........... | 14·6 | 52·88 | 17·45 | 213·30 |

Carbon broke at middle of loop 9.00 P.M., April 20, 1885. Discoloration, 4½.

## *Woodhouse and Rawson Lamp, No. 4.*

(Reduction Factor, 1·05. Resistance Cold, 108.)

| Date. | Volts. | Ampéres. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 55·15 | 1·057 | 58·29 | 17·2 | 17·99 | 3·24 | 21·27 | 52·18 | 1·00 | 1·00 |
| 11 | ............ | ............ | ............ | 22·3 | 23·4 | ............ | 27·7 | ............ | 3·30 | 4·30 |
| 12 | ............ | ............ | ............ | ............ | ............ | ............ | ............ | ............ | 24·00 | 28·30 |
| 13 | 53·40 | 1·023 | 54·62 | 12·7 | 13·3 | ............ | 15·7 | 52·20 | 24·00 | 52·30 |
| 14 | 53·70 | 1·015 | 54·50 | 12·5 | 13·2 | ............ | 15·6 | 52·91 | 24·00 | 76·30 |
| 15 | 54·15 | ............ | ............ | ............ | ............ | ............ | ............ | ............ | 24·00 | 100·30 |
| 16 | ............ | ............ | ............ | ............ | ............ | ............ | ............ | ............ | 21·45 | 122·15 |
| 17 | 56·05 | ............ | ............ | ............ | ............ | ............ | ............ | ............ | 24·00 | 146·15 |
| 18 | 55·60 | ·987 | 54·87 | 12·3 | 12·9 | ............ | 15·3 | 56·33 | 24·00 | 170·15 |
| 19 | 56·50 | ............ | ............ | ............ | ............ | ............ | ............ | ............ | 24·00 | 194·15 |
| 20 | ............ | ............ | ............ | ............ | ............ | ............ | ............ | ............ | 8·45 | 203·00 |

Carbon broke at side of loop 8.40 A.M., April 20, 1885. Discoloration, 4½.

## *Woodhouse and Rawson Lamp, No. 5.*

(Reduction Factor, 1·14. Resistance Cold, 118.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 55·40 | 1·000 | 55·40 | 12·3 | 13·97 | 3·96 | 16·31 | 55·40 | 0·45 | 0·45 |
| 11 | ............ | ............ | ............ | 17·0 | 19·4 | ............ | 22·7 | ............ | 3·45 | 4·30 |
| 12 | ............ | ............ | ............ | ............ | ............ | ............ | ............ | ............ | 24·00 | 28·30 |
| 13 | 53·35 | ·998 | 53·24 | 11·3 | 12·9 | ............ | 15·1 | 53·46 | 24·00 | 52·30 |
| 14 | 53·80 | 1·003 | 53·96 | 11·5 | 13·1 | ............ | 15·3 | 53·64 | 24·00 | 76·30 |
| 15 | 54·15 | ............ | ............ | ............ | ............ | ............ | ............ | ............ | 24·00 | 100·30 |
| 16 | 54·25 | 1·002 | 54·35 | 13·2 | 15·0 | ............ | 17·5 | 54·14 | 24·00 | 124·30 |
| 17 | 54·25 | ............ | ............ | ............ | ............ | ............ | ............ | ............ | 24·00 | 148·30 |
| 18 | 54·15 | ·993 | 53·77 | 11·0 | 12·5 | ............ | 14·6 | 54·53 | 24·00 | 172·30 |
| 19 | 54·95 | ............ | ............ | ............ | ............ | ............ | ............ | ............ | 24·00 | 196·30 |
| 20 | 53·05 | ·967 | 51·30 | 10·3 | 11·7 | ............ | 13·7 | 54·86 | 20·45 | 217·15 |
| 21 | 55·05 | ............ | ............ | ............ | ............ | ............ | ............ | ............ | 24·00 | 241·15 |
| 22 | 54·80 | ·987 | 54·08 | 11·5 | 13·1 | ............ | 15·3 | 55·52 | 24·00 | 265·15 |
| 23 | 54·95 | ·986 | 54·18 | 9·0 | 10·3 | ............ | 12·0 | 55·73 | 24·00 | 289·15 |
| 24 | 54·95 | ............ | ............ | ............ | ............ | ............ | ............ | ............ | 24·00 | 313·15 |
| *25 | 55·10 | ·975 | 53·72 | 9·4 | 10·7 | ............ | 12·5 | 56·51 | 24·00 | 337·15 |
| 26 | 55·20 | ............ | ............ | ............ | ............ | ............ | ............ | ............ | 21·00 | 358·15 |
| *27 | 54·70 | ·964 | 52·73 | 8·4 | 9·6 | ............ | 11·2 | 56·74 | 24·00 | 382·15 |
| *28 | 55·10 | ·962 | 53·00 | 7·5 | 8·6 | ............ | 10·1 | 57·29 | 24·00 | 406·15 |
| *29 | 55·20 | ·959 | 52·93 | 7·7 | 8·8 | ............ | 16·3 | 57·56 | 24·00 | 430·15 |
| 30 | ............ | ............ | ............ | ............ | ............ | ............ | ............ | ............ | 9·30 | 439·45 |

Carbon broke at middle of loop 9.30 A.M., April 30, 1885. Discoloration, 4½.

## *Woodhouse and Rawson Lamp, No. 6.*

(Reduction Factor, 1·12. Resistance Cold, 124.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Candl. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 55·30 | ·936 | 51·76 | 11·7 | 13·11 | 3·94 | 14·76 | 59·08 | 0·45 | 0·45 |
| 11 | ...... .... | ........... | ........... | 11·4 | 12·8 | ........... | 14·5 | ........... | 3·45 | 4·30 |
| 12 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | .... ....... | 24·00 | 28·30 |
| 13 | 53·75 | ·899 | 48·32 | 9·3 | 10·4 | ........... | 11·8 | 59·79 | 24·00 | 52·30 |
| 14 | 53·00 | ·887 | 47·01 | 9·1 | 10·2 | ........... | 11·5 | 59·75 | 24·00 | 76·30 |
| 15 | 53·65 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 100·30 |
| 16 | 53·85 | ·898 | 48·35 | 10·7 | 11·9 | ........... | 13·4 | 59·97 | 24·00 | 124·30 |
| 17 | 54·80 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 148·30 |
| 18 | 54·35 | ·893 | 48·53 | 10·5 | 11·8 | ........... | 13·3 | 60·86 | 24·00 | 172·30 |
| 19 | 54·55 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 196·30 |
| 20 | 52·30 | ·857 | 44·82 | 8·7 | 9·7 | ........... | 11·0 | 61·03 | 20·45 | 217·15 |
| 21 | 53·10 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 241·15 |
| 22 | 52·85 | ·862 | 45·55 | 8·5 | 9·5 | ........... | 10·7 | 61·31 | 24·00 | 265·15 |
| 23 | 55·05 | ·886 | 48·77 | 9·7 | 10·9 | ........... | 12·3 | 62·13 | 24·00 | 289·15 |
| 24 | 54·95 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 313·15 |
| *25 | 55·50 | ·885 | 49·11 | 8·8 | 9·9 | ........... | 11·1 | 62·71 | 24·00 | 337·15 |
| 26 | 55·10 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 21·00 | 358·15 |
| *27 | 55·05 | ·870 | 47·89 | 8·6 | 9·6 | ........... | 10·8 | 63·28 | 24·00 | 382·15 |
| 28 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 13·00 | 395·15 |

Carbon broke at shank 1.00 P. M , April 28, 1885. Discoloration, 4.

## *Woodhouse and Rawson Lamp, No. 7.*

(Reduction Factor, 1·00 Resistance Cold, 132.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885, April. | 55·90 | ·914 | 51·09 | 15·5 | 15·53 | 3·29 | 19·45 | 61·16 | 0·45 | 0·45 |
| 11 | ........ | ........ | ........ | 16·6 | 16·6 | ........ | 20·8 | ........ | 3·45 | 4·30 |
| 12 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 28·30 |
| 13 | 55·25 | ·901 | 49·78 | 13·0 | 13·0 | ........ | 16·3 | 61·32 | 24·00 | 52·30 |
| 14 | 56·20 | ·887 | 49·85 | 12·7 | 12·7 | ........ | 15·9 | 63·36 | 24·00 | 76·30 |
| 15 | 56·30 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 100·30 |
| 16 | 55·90 | ·910 | 50·86 | 16·4 | 16·4 | ........ | 20·5 | 61·43 | 24·00 | 124·30 |
| 17 | 56·00 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 148·30 |
| 18 | 56·40 | ·895 | 50·47 | 15·0 | 15·0 | ........ | 18·8 | 63·02 | 24·00 | 172·30 |
| 19 | 57·10 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 196·30 |
| 20 | 55·20 | ·839 | 46·31 | 11·8 | 11·8 | ........ | 14·8 | 65·79 | 20·45 | 217·15 |
| 21 | 56·65 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 241·15 |
| 22 | 56·80 | ·864 | 49·07 | 12·4 | 12·4 | ........ | 15·5 | 65·74 | 24·00 | 265·15 |
| 23 | 55·10 | ·824 | 45·40 | 10·1 | 10·1 | ........ | 12·6 | 66·87 | 24·00 | 289·15 |
| 24 | 54·95 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 313·15 |
| *25 | 55·55 | ·818 | 45·43 | 8·5 | 8·5 | ........ | 10·6 | 67·91 | 24·00 | 337·15 |
| 26 | 55·20 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 21·00 | 358·15 |
| *27 | 54·95 | ·806 | 44·29 | 8·4 | 8·4 | ........ | 10·5 | 68·18 | 24·00 | 382·15 |
| *28 | 55·30 | ·796 | 44·01 | 7·0 | 7·0 | ........ | 8·8 | 69·47 | 24·00 | 406·15 |
| *29 | 55·45 | ·793 | 43·97 | 7·2 | 7·2 | ........ | 9·0 | 69·93 | 16·30 | 422·45 |

Carbon broke at side of loop 4.25 P. M., April 29, 1885. Discoloration 4½.

## *Woodhouse and Rawson Lamp, No. 8, 55 Volts.*

(Reduction Factor, 1·07. Resistance Cold, 116.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 56·05 | 1·025 | 57·45 | 14·0 | 15·05 | 3·81 | 18·28 | 54·68 | 2·00 | 2·00 |
| 11 | ........ | ........ | ........ | 18·6 | 19·9 | ........ | 24·1 | ........ | 3·30 | 5·30 |
| 12 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 29·30 |
| 13 | 55·20 | 1·022 | 56·41 | 12·5 | 13·4 | ........ | 16·2 | 54·01 | 24·00 | 53·30 |
| 14 | 55·75 | 1·019 | 56·80 | 12·9 | 13·8 | ........ | 16·7 | 54·71 | 24·00 | 77·30 |
| 15 | 56·30 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 101·30 |
| 16 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 16·15 | 117·45 |

Carbon broke at side of loop 4.15 P. M., April 16, 1885. Discoloration, 3.

## *Woodhouse and Rawson Lamp, No. 9.*

(Reduction Factor, 1·00. Resistance Cold, 106.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 55·95 | 1·125 | 62·94 | 18·50 | 18·43 | 3·41 | 22·01 | 49·73 | 1·00 | 1·00 |
| 11 | ........... | ........... | ........... | 17·2 | 17·2 | ........... | 20·5 | ........... | 3·45 | 4·45 |
| 12 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 28·45 |
| 13 | 52·95 | 1·082 | 57·29 | 12·8 | 12·8 | ........... | 15·2 | 48·94 | 24·00 | 52·45 |
| 14 | 53·55 | 1·093 | 58·53 | 13·2 | 13·2 | ........... | 15·7 | 48·99 | 24·00 | 76·45 |
| 15 | 55·60 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 100·45 |
| 16 | 56·30 | 1·120 | 63·06 | 17·3 | 17·3 | ........... | 20·6 | 50·27 | 24·00 | 124·45 |
| 17 | 56·70 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 148·45 |
| 18 | 54·00 | 1·052 | 56·80 | 10·8 | 10·8 | ........... | 12·8 | 51·33 | 24·00 | 172·45 |
| 19 | 54·70 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 196·45 |
| 20 | 53·10 | 1·024 | 54·37 | 9·6 | 9·6 | ........... | 11·4 | 51·86 | 20·45 | 217·30 |
| 21 | 54·55 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 241·30 |
| 22 | 55·00 | 1·047 | 57·58 | 10·5 | 10·5 | ........... | 12·5 | 52·53 | 24·00 | 265·30 |
| 23 | 55·25 | 1·043 | 57·62 | 9·1 | 9·1 | ........... | 10·8 | 52·97 | 24·00 | 289·30 |
| 24 | 55·30 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 313·30 |
| *25 | 55·30 | 1·030 | 56·96 | 8·4 | 8·4 | ........... | 10·0 | 53·69 | 24·00 | 337·30 |
| 26 | 55·10 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 21·00 | 358·30 |
| *27 | 54·85 | 1·015 | 55·67 | 7·8 | 7·8 | ........... | 9·3 | 54·04 | 24·00 | 382·30 |
| *28 | 55·25 | 1·018 | 56·24 | 6·5 | 6·5 | ........... | 7·7 | 54·27 | 24·00 | 406·30 |
| *29 | 55·45 | 1·020 | 56·55 | 6·7 | 6·7 | ........... | 8·0 | 54·36 | 24·00 | 430·30 |
| 30 | 55·25 | 1·012 | 55·91 | 8·7 | 8·7 | ........... | 10·4 | 54·60 | 24·00 | 454·30 |
| May. | | | | | | | | | | |
| 1 | 55·35 | 1·011 | 55·95 | 8·0 | 8·0 | ........... | 9·5 | 54·75 | 24·00 | 478·30 |
| 2 | 55·10 | 1·002 | 55·21 | 7·0 | 7·0 | ........... | 8·3 | 54·99 | 24·00 | 502·30 |
| 3 | 54·85 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 526·30 |
| 4 | 55·10 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 550·30 |
| 5 | 55·10 | ·995 | 54·82 | 7·4 | 7·4 | ........... | 8·8 | 55·38 | 24·00 | 574·30 |
| 6 | 55·00 | ·986 | 54·23 | 6·7 | 6·7 | ........... | 8·0 | 55·78 | 23·30 | 598·00 |
| 7 | 55·10 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 622·00 |
| 8 | 55·25 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 646·00 |
| 9 | 55·10 | ·982 | 54·10 | 7·3 | 7·3 | ........... | 8·7 | 56·11 | 24·00 | 670·00 |
| 10 | 55·40 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 694·00 |
| 11 | 55·50 | ·984 | 54·61 | 7·0 | 7·0 | ........... | 8·3 | 56·40 | 21·30 | 715·30 |

Carbon broke at side of loop 9.30 P.M., May 11, 1885. Discoloration, 5.

## *Woodhouse and Rawson Lamp, No. 10.*

(Reduction Factor, 1·18. Resistance Cold, 139.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 56·00 | ·805 | 45·08 | 10·40 | 12·19 | 3·69 | 14·38 | 69·57 | 1·30 | 1·30 |
| 22 | ........... | ........... | ........... | ........... | .... ...... | ........... | ........... | ........... | 6·15 | 7·45 |
| 23 | 55·10 | ·781 | 43·03 | 10·6 | 12·5 | ........... | 14·7 | 70·55 | 24·00 | 31·45 |
| 24 | 55·30 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 55·45 |
| 25 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 13·00 | 68·45 |

Carbon broke at side of loop 1.00 P. M., April 25, 1885. Discoloration, 2½.

## *Woodhouse and Rawson Lamp, No. 18 B.*

(Reduction Factor, 1·19. Resistance Cold, 115.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 55·25 | 1·004 | 55·47 | 12·0 | 14·33 | 3·87 | 17·41 | 55·03 | 1·15 | 1·15 |
| 11 | ........... | ........... | ........... | 13·6 | 16·2 | ........... | 19·6 | ........... | 3·45 | 5·00 |
| 12 | ........... | ........... | ........... | ...... ... | .......... . | ........... | ........... | ........... | 24·00 | 29·00 |
| 13 | 55·00 | 1·003 | 55·17 | 12·3 | 14·7 | ........... | 17·8 | 54·84 | 24·00 | 53·00 |
| 14 | 55·00 | 1·000 | 55·00 | 11·9 | 14·1 | ........... | 17·1 | 55·00 | 24·00 | 77·00 |
| 15 | 55·10 | ........... | ........... | ........... | ........... | ........... | ..... ...... | ........... | 24·00 | 101·00 |
| 16 | 55·65 | 1·004 | 55·87 | 14·7 | 17·5 | ........... | 21·2 | 55·43 | 24·00 | 125·00 |
| 17 | 55·35 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 149·05 |
| 18 | 55·35 | ·991 | 54·85 | 13·3 | 15·8 | ........... | 19·1 | 55·85 | 24·00 | 173·00 |
| 19 | 56·45 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 197·00 |
| 20 | 54·85 | ·972 | 53·31 | 12·8 | 15·2 | ........... | 18·4 | 56·43 | 20·45 | 217·45 |
| 21 | 54·35 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 241·45 |
| 22 | 54·50 | ·956 | 52·10 | 10·8 | 12·9 | ........... | 15·6 | 57·01 | 24·00 | 265·45 |
| 23 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 11·45 | 277·30 |

Carbon broke at side of loop 11.45 A. M., April 23, 1885. Discoloration, 3½.

## Woodhouse and Rawson, Second Lot.

### *Woodhouse and Rawson Lamp, No. 30.**

(Reduction Factor, 1·08. Resistance Cold, 100.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles, Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 55·00 | 1·167 | 64·18 | 17·18 | 18·52 | 3·46 | 22·73 | 47·13 | 1·00 | 1·00 |
| 12 | 54·60 | 1·154 | 63·00 | 20·2 | 21·8 | ........... | 26·8 | 47·31 | 8·15 | 9·15 |
| 13 | 54·85 | 1·168 | 64·06 | 20·4 | 22·0 | ........... | 27·1 | 46·96 | 23·30 | 32·45 |
| 14 | 54·95 | 1·172 | 64·40 | 21·6 | 23·3 | ........... | 28·7 | 46·89 | 24·00 | 56·45 |
| *15 | 55·00 | 1·166 | 64·13 | 23·9 | 25·8 | ........... | 31·7 | 47·17 | 24·00 | 80·45 |
| 16 | 55·10 | 1·166 | 64·24 | 21·6 | 23·3 | ........... | 28·7 | 47·26 | 24·00 | 104·45 |
| 17 | 55·70 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 128·45 |
| 18 | 55·45 | 1·154 | 63·99 | 20·1 | 21·7 | ........... | 26·7 | 48·05 | 24·00 | 152·45 |
| 19 | 55·25 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 176·45 |
| 20 | 55·20 | 1·140 | 62·92 | 16·8 | 18·1 | ........... | 22·3 | 48·12 | 24·00 | 200·45 |
| 21 | 54·85 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 224·45 |
| 22 | 54·75 | 1·120 | 61·32 | 15·5 | 16·7 | ........... | 20·6 | 48·88 | 24·00 | 248·45 |
| 23 | 54·65 | 1·119 | 61·15 | 13·2 | 14·3 | ........... | 17·6 | 48·84 | 24·00 | 272·45 |
| 24 | 55·30 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 296·45 |
| *25 | 54·90 | 1·117 | 61·32 | 9·7 | 10·5 | ........... | 12·9 | 49·15 | 24·00 | 320·45 |
| 26 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 11·30 | 332·15 |

Resistance Cold, 101. Discoloration, 4.

### *Woodhouse and Rawson Lamp, No. 31.*

(Reduction Factor, 0·94. Resistance Cold, 102.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles, Mean Horizontal. | Resistance, Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 55·05 | 1·182 | 65·07 | 18·48 | 17·28 | 3·76 | 29·93 | 46·57 | 0·45 | 0·45 |
| 12 | 55·00 | 1·182 | 65·01 | 19·0 | 17·9 | ........... | 21·7 | 46·53 | 8·00 | 8·45 |
| 13 | 55·10 | ........... | ........... | 20·0 | 18·8 | ........... | 22·7 | ........... | 23·30 | 32·15 |
| 14 | 55·15 | 1·183 | 65·24 | 21·4 | 20·1 | ........... | 24·3 | 46·62 | 24·00 | 56·15 |
| *15 | 55·25 | 1·178 | 65·08 | 22·6 | 21·2 | ........... | 25·7 | 46·90 | 24·00 | 80·15 |
| 16 | 55·50 | 1·173 | 65·10 | 20·8 | 19·6 | ........... | 23·7 | 47·31 | 24·00 | 104·15 |
| 17 | 55·45 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 128·15 |
| 18 | 54·85 | 1·146 | 62·85 | 17·9 | 16·8 | ........... | 20·3 | 47·86 | 24·00 | 152·15 |
| 19 | 55·25 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 176·15 |
| 20 | 55·20 | 1·139 | 62·87 | 15·7 | 14·8 | ........... | 17·9 | 48·46 | 24·00 | 200·15 |
| 21 | 54·90 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 224·15 |
| 22 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 3·00 | 227·15 |

Carbon broke at side of loop 3.00 A. M., May 22, 1885. Discoloration, 4.

*These lamps, Nos. 30–90 inclusive, were marked 50 volts, but tested at 55.

*Woodhouse and Rawson Lamp, No. 32.*

(Reduction Factor, 1·07. Resistance Cold, 100.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 55·00 | 1·195 | 65·72 | 16·28 | 17·36 | 3·78 | 21·28 | 46·02 | 0·30 | 0·30 |
| 12 | 54·85 | 1·177 | 64·56 | 18·3 | 19·6 | ......... | 24·1 | 46·60 | 8·00 | 8·30 |
| 13 | 54·95 | ......... | ......... | 16·4 | 17·5 | ......... | 21·5 | ......... | 23·30 | 32·00 |
| 14 | 54·60 | 1·186 | 64·75 | 18·6 | 19·9 | ......... | 24·5 | 46·04 | 24·00 | 56·00 |
| *15 | 55·00 | 1·187 | 65·28 | 20·6 | 22·0 | ......... | 27·1 | 46·34 | 24·00 | 80·00 |
| 16 | 54·60 | 1·181 | 64·48 | 17·6 | 18·8 | ......... | 23·1 | 46·23 | 24·00 | 104·00 |
| 17 | 55·40 | ......... | ......... | ......... | ......... | ......... | ......... | ......... | 24·00 | 128·00 |
| 18 | 55·00 | 1·186 | 65·22 | 17·5 | 18·7 | ......... | 23·0 | 46·37 | 24·00 | 152·00 |
| 19 | 55·25 | ......... | ......... | ......... | ......... | ......... | ......... | ......... | 24·00 | 176·00 |
| 20 | 55·00 | 1·184 | 65·12 | 15·3 | 16·4 | ......... | 20·2 | 46·45 | 24·00 | 200·00 |
| 21 | 54·95 | ......... | ......... | ......... | ......... | ......... | ......... | ......... | 24·00 | 224·00 |
| 22 | 54·70 | 1·170 | 64·00 | 14·0 | 15·0 | ......... | 18·5 | 46·75 | 24·00 | 248·00 |
| 23 | 54·75 | 1·168 | 63·94 | 12·6 | 13·5 | ......... | 16·6 | 46·88 | 24·00 | 272·00 |
| 24 | 55·45 | ......... | ......... | ......... | ......... | ......... | ......... | ......... | 24·00 | 296·00 |
| *25 | 55·00 | 1·169 | 64·29 | 11·1 | 11·9 | ......... | 14·6 | 47·05 | 24·00 | 320·00 |
| 26 | ......... | ......... | ......... | ......... | ......... | ......... | ......... | ......... | 11·30 | 331·00 |

Resistance Cold, 100. Discoloration, 3½.

*Woodhouse and Rawson Lamp, No. 33.*

(Reduction Factor, 1·00. Resistance Cold, 101.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 55·05 | 1·188 | 65·40 | 19·05 | 19·01 | 3·44 | 22·67 | 46·43 | 0·30 | 0·30 |
| 12 | 55·05 | 1·175 | 64·68 | 18·7 | 18·7 | ......... | 22·3 | 46·85 | 7·45 | 8·15 |
| 13 | 54·95 | ......... | ......... | 18·1 | 18·1 | ......... | 21·5 | ......... | 23·30 | 31·45 |
| 14 | 54·75 | 1·180 | 64·60 | 19·4 | 19·4 | ......... | 23·1 | 46·40 | 24·00 | 55·45 |
| *15 | 55·00 | 1·197 | 65·83 | 21·5 | 21·5 | ......... | 25·6 | 45·95 | 24·00 | 79·45 |
| 16 | 54·50 | 1·198 | 65·29 | 19·8 | 19·8 | ......... | 23·6 | 45·49 | 24·00 | 103·45 |
| 17 | 55·30 | ......... | ......... | ......... | ......... | ......... | ......... | ......... | 24·00 | 127·45 |
| 18 | 55·10 | 1·200 | 66·12 | 18·8 | 18·8 | ......... | 22·4 | 45·92 | 24·00 | 151·45 |
| 19 | 55·30 | ......... | ......... | ......... | ......... | ......... | ......... | ......... | 24·00 | 175·45 |
| 20 | 55·15 | 1·195 | 65·90 | 17·4 | 17·4 | ......... | 20·7 | 46·15 | 24·00 | 199·45 |
| 21 | 54·95 | ......... | ......... | ......... | ......... | ......... | ......... | ......... | 24·00 | 223·45 |
| 22 | 54·65 | 1·171 | 63·99 | 16·3 | 16·3 | ......... | 19·4 | 46·67 | 24·00 | 247·45 |
| 23 | 54·70 | 1·170 | 64·00 | 14·2 | 14·2 | ......... | 16·9 | 46·75 | 24·00 | 271·45 |
| 24 | 55·50 | ......... | ......... | ......... | ......... | ......... | ......... | ......... | 24·00 | 295·45 |
| *25 | 55·10 | 1·169 | 64·41 | 11·1 | 11·1 | ......... | 13·2 | 47·13 | 24·00 | 319·45 |
| 26 | ......... | ......... | ......... | ......... | ......... | ......... | ......... | ......... | 11·30 | 331·15 |

Resistance Cold, 102. Discoloration, 4.

## *Woodhouse and Rawson Lamp, No. 34.*

(Reduction Factor, 1·01  Resistance Cold, 100.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles, Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 55·00 | 1·147 | 63·08 | 16·68 | 16·91 | 3·73 | 20·78 | 47·95 | 0·30 | 0·30 |
| 12 | 54·90 | 1·139 | 62·53 | 18·3 | 18·5 | ........ | 22·8 | 48·20 | 7·30 | 8·00 |
| 13 | 54·80 | ........ | ........ | 17·6 | 17·8 | ........ | 21·9 | ........ | 23·30 | 31·30 |
| 14 | 55·00 | 1·145 | 62·97 | 17·9 | 18·1 | ........ | 22·3 | 48·03 | 24·00 | 55·30 |
| *15 | 55·00 | 1·139 | 62·64 | 21·4 | 21·6 | ........ | 26·6 | 48·29 | 24·00 | 79·30 |
| 16 | 54·85 | 1·138 | 62·42 | 19·0 | 19·2 | ........ | 23·6 | 48·20 | 24·00 | 103·30 |
| 17 | 55·40 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 127·30 |
| 18 | 55·00 | 1·134 | 62·36 | 18·2 | 18·4 | ........ | 22·6 | 48·50 | 24·00 | 151·30 |
| 19 | 55·30 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 175·30 |
| 20 | 55·15 | 1·127 | 62·15 | 16·6 | 16·8 | ........ | 20·7 | 48·94 | 24·00 | 199·30 |
| 21 | 54·75 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 223·30 |
| 22 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 11·00 | 234·30 |

Carbon broke at side of loop near shank 11.00 A. M., May 22, 1885. Discoloration, 3.

## *Woodhouse and Rawson Lamp, No. 35.*

(Reduction Factor, 0·93.  Resistance Cold, 101.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles, Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 54·95 | 1·139 | 62·58 | 21·14 | 19·56 | 3·20 | 23·53 | 48.24 | 0·45 | 0·45 |
| 12 | 55·00 | 1·133 | 62·31 | 22·0 | 20·5 | ........ | 24·6 | 48·54 | 7·30 | 8·15 |
| 13 | 55·20 | ........ | ........ | 22·2 | 20·6 | ........ | 24·7 | ........ | 23·30 | 31·45 |
| 14 | 54·90 | 1·117 | 61·32 | 22·3 | 20·7 | ........ | 24·8 | 49·15 | 24·00 | 55·45 |
| *15 | 55·00 | 1·133 | 62·31 | 23·6 | 21·9 | ........ | 26·3 | 48·54 | 24·00 | 79·45 |
| 16 | 55·15 | 1·107 | 61·05 | 22·3 | 20·7 | ........ | 24·8 | 49·82 | 24·00 | 103·45 |
| 17 | 55·05 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 127·45 |
| 18 | 54·85 | 1·094 | 60·00 | 19·7 | 18·3 | ........ | 21·9 | 50·14 | 24·00 | 151·45 |
| 19 | 55·10 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 175·45 |
| 20 | 54·95 | 1·087 | 59·73 | 18·3 | 17·0 | ........ | 20·4 | 50·55 | 24·00 | 199·45 |
| 21 | 54·90 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 223·45 |
| 22 | 54·80 | 1·071 | 58·69 | 16·5 | 15·3 | ........ | 18·4 | 51·17 | 24·00 | 247·45 |
| 23 | 54·95 | 1·071 | 58·85 | 14·4 | 13·4 | ........ | 16·1 | 51·31 | 24·00 | 271·45 |
| 24 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 0·30 | 272·15 |

Carbon broke at side of loop near shank 12.30 A. M., May 24, 1885. Discoloration, 3½.

## *Woodhouse and Rawson Lamp, No. 36.*

(Reduction Factor, 0·97. Resistance Cold, 99.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 55·00 | 1·191 | 65·50 | 22·13 | 21·41 | 3·05 | 25·98 | 46·18 | 0·45 | 0·45 |
| 12 | 54·70 | 1·180 | 64·54 | 23·9 | 23·2 | ........... | 28·1 | 46·36 | 7·00 | 7·45 |
| 13 | 55·15 | ........... | ........... | 22·2 | 21·5 | ........... | 26·0 | ........... | 23·30 | 31·15 |
| 14 | 55·30 | 1·194 | 66·02 | 24·1 | 23·4 | ........... | 28·3 | 46·32 | 24·00 | 55·15 |
| *15 | 54·85 | 1·175 | 64·45 | 23·9 | 23·2 | ........... | 28·1 | 46·68 | 24·00 | 79·15 |
| 16 | 55·25 | 1·177 | 65·03 | 22·0 | 21·3 | ........... | 25·8 | 46·94 | 24·00 | 103·15 |
| 17 | 55·15 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 127·15 |
| 18 | 54·95 | 1·157 | 63·57 | 18·1 | 17·6 | ........... | 21·3 | 47·49 | 24·00 | 151·15 |
| 19 | 55·25 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 175·15 |
| 20 | 54·95 | 1·149 | 63·13 | 15·5 | 15·0 | ........... | 18·2 | 47·82 | 24·00 | 199·15 |
| 21 | 54·85 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 223·15 |
| 22 | 54·70 | 1·140 | 62·35 | 13·7 | 13·3 | ........... | 16·1 | 47·98 | 24·00 | 247·15 |
| 23 | 54·70 | 1·137 | 62·19 | 12·4 | 12·0 | ........... | 14·5 | 48·11 | 24·00 | 271·15 |
| 24 | 55·45 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 295·15 |
| *25 | 55·00 | 1·135 | 62·42 | 9·4 | 9·1 | ........... | 11·0 | 48·46 | 24·00 | 319·15 |
| 26 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 11·30 | 330·45 |

Resistance Cold, 102. Discoloration, 4.

## *Woodhouse and Rawson Lamp, No. 37.*

(Reduction Factor, 1·04. Resistance Cold, 100.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 55·00 | 1·185 | 65·17 | 18·03 | 18·74 | 3·47 | 22·93 | 46·41 | 0·30 | 0·30 |
| 12 | 55·00 | 1·181 | 64·95 | 20·3 | 21·1 | ........... | 25·7 | 46·57 | 7·15 | 7·45 |
| 13 | 55·05 | ........... | ........... | 19·4 | 20·2 | ........... | 24·6 | ........... | 23·30 | 31·15 |
| 14 | 55·00 | 1·186 | 65·22 | 20·4 | 21·2 | ........... | 25·9 | 46·37 | 24·00 | 55·15 |
| *15 | 55·00 | 1·180 | 64·90 | 20·0 | 20·8 | ........... | 25·4 | 46·61 | 24·00 | 79·15 |
| 16 | 55·25 | 1·182 | 65·30 | 19·5 | 20·3 | ........... | 24·8 | 46·74 | 24·00 | 103·15 |
| 17 | 55·25 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 127·15 |
| 18 | 55·10 | 1·165 | 64·19 | 17·1 | 17·8 | ........... | 21·7 | 47·30 | 24·00 | 151·15 |
| 19 | 55·30 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 175·15 |
| 20 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 1·30 | 176·45 |

Carbon broke at side of loop 1.30 A. M., May 20, 1885. Discoloration, 3½.

## *Woodhouse and Rawson Lamp, No. 38.*

(Reduction Factor, 0·99. Resistance Cold, 100.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 54·95 | 1·197 | 65·77 | 18·05 | 17·84 | 3·69 | 20·70 | 45·91 | 0·45 | 0·45 |
| 12 | 54·70 | 1·194 | 65·31 | 18·6 | 18·4 | ........... | 21·3 | 45·81 | 7·15 | 8·00 |
| 13 | 54·80 | ........... | ........... | 19·5 | 19·3 | ........... | 22·4 | ........... | 23·30 | 31·30 |
| 14 | 54·85 | 1·219 | 66·86 | 19·0 | 18·8 | ........... | 21·8 | 45·00 | 24·00 | 55·30 |
| *15 | ........... | 1·217 | ........... | 19·9 | 19·7 | ........... | 22·9 | ........... | 24·00 | 79·30 |
| 16 | 54·75 | 1·221 | 66·85 | 18·4 | 18·2 | ........... | 21·1 | 44·84 | 24·00 | 103·30 |
| 17 | 54·95 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 127·30 |
| 18 | 55·20 | 1·229 | 67·84 | 18·6 | 18·4 | ........... | 21·3 | 44·92 | 24·00 | 151·30 |
| 19 | 55·25 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 175·30 |
| 20 | 55·30 | 1·220 | 67·46 | 17·6 | 17·4 | ........... | 20·2 | 45·33 | 24·00 | 199·30 |
| 21 | 55·10 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 223·30 |

Carbon broke at middle of loop 11.55 P. M., May 21, 1885. Discoloration, 4½.

## *Woodhouse and Rawson Lamp, No. 00.*†

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | | | | | | | | | | |
| 12 | 54·95 | 1·151 | 63·24 | 20·0 | ........... | ........... | ........... | 47·74 | 6·45 | 6·45 |
| 13 | 55·35 | ........... | ........... | 20·0 | ........... | ........... | ........... | ........... | 23·30 | 30·15 |
| 14 | 55·40 | 1·150 | 63·71 | 19·6 | ........... | ........... | ........... | 48·17 | 24·00 | 54·15 |
| *15 | 54·95 | 1·137 | 62·47 | 20·1 | ........... | ........... | ........... | 48·33 | 24·00 | 78·15 |
| 16 | 55·05 | 1·137 | 62·59 | 18·4 | ........... | ........... | ........... | 48·42 | 24·00 | 102·15 |
| 17 | 55·65 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 126·15 |
| 18 | 55·10 | 1·119 | 61·65 | 18·1 | ........... | ........... | ........... | 49·24 | 24·00 | 150·15 |
| 19 | 55·35 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 174·15 |
| 20 | 54·80 | 1·093 | 59·89 | 15·3 | ........... | ........... | ........... | 50·14 | 24·00 | 198·15 |
| 21 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 14·15 | 212·30 |

Carbon broke at side of loop near shank 2.15 P. M., May 21, 1885. Discoloration, 4.

† Lamp 39 having been disabled before duration test began, this lamp on which no efficiency measurements had been made was substituted for it.

# White Lamps, 50 Volts.

## *White Lamp, No. 1.*

(Reduction Factor, 0·85.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 50·00 | 1·033 | 51·65 | 12·78 | 10·80 | 4·78 | 13·08 | 48·40 | 0·45 | 0·45 |
| 13 | 49·20 | 1·062 | 52·25 | 16·1 | 13·7 | ........... | 16·6 | 46·33 | 12·00 | 12·45 |
| 14 | 50·05 | 1·102 | 55·15 | 18·5 | 15·7 | ........... | 19·0 | 45·42 | 24·00 | 36·45 |
| *15 | 49·90 | 1·115 | 55·63 | 22·6 | 19·2 | ........... | 23·2 | 44·75 | 24·00 | 60·45 |
| 16 | 49·80 | 1·122 | 55·87 | 20·0 | 17·0 | ........... | 20·6 | 44·39 | 24·00 | 84·45 |
| 17 | 49·95 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 108·45 |
| 18 | 49·60 | 1·122 | 55·65 | 20·5 | 17·4 | ........... | 21·1 | 44·21 | 24·00 | 132·45 |
| 19 | 50·20 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 156·45 |
| 20 | 49·85 | 1·132 | 56·43 | 20·2 | 17·2 | ........... | 20·2 | 44·04 | 24·00 | 180·45 |
| 21 | 50·20 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 204·45 |
| 22 | 49·90 | 1·132 | 56·48 | 19·7 | 16·7 | ........... | 20·2 | 44·08 | 24·00 | 228·45 |
| 23 | 49·85 | 1·129 | 56·28 | 18·5 | 15·7 | ........... | 19·0 | 44·16 | 24·00 | 252·45 |
| 24 | 50·10 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 276·45 |
| *25 | 49·90 | 1·127 | 56·23 | 13·8 | 11·7 | ........... | 14·2 | 44·28 | 24·00 | 300·45 |
| 26 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 11·30 | 312·15 |

Resistance Cold, 94. Discoloration, 3½.

## *White Lamp, No. 2.*

(Reduction Factor, 0·85.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 50·00 | 1·005 | 50·25 | 12·93 | 10·97 | 4·58 | 13·20 | 49·75 | 0·30 | 0·30 |
| 13 | 49·90 | 1·023 | 51·04 | 15·6 | 13·3 | ........... | 16·0 | 48·78 | 11·45 | 12·15 |
| 14 | 49·85 | 1·041 | 51·89 | 17·5 | 14·9 | ........... | 17·9 | 47·89 | 24·00 | 36·15 |
| *15 | 50·25 | 1·049 | 52·71 | 19·8 | 16·8 | ........... | 20·2 | 47·90 | 24·00 | 60·15 |
| 16 | 49·80 | 1·057 | 52·63 | 19·3 | 16·4 | ........... | 19·7 | 47·12 | 24·00 | 84·15 |
| 17 | 50·05 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 108·15 |
| 18 | 49·75 | 1·054 | 52·43 | 18·3 | 15·6 | ........... | 18·7 | 47·20 | 24·00 | 132·15 |
| 19 | 49·95 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 156·15 |
| 20 | 50·00 | 1·055 | 52·75 | 18·6 | 15·8 | ........... | 19·0 | 47·39 | 24·00 | 180·15 |
| 21 | 50·10 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 204·15 |
| 22 | 50·10 | 1·052 | 52·70 | 17·6 | 15·0 | ........... | 18·0 | 47·63 | 24·00 | 228·15 |
| 23 | 50·05 | 1·056 | 52·85 | 16·9 | 14·4 | ........... | 17·3 | 47·40 | 24·00 | 252·15 |
| 24 | 50·15 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 276·15 |
| *25 | 50·10 | 1·044 | 52·30 | 12·8 | 10·9 | ........... | 13·1 | 47·99 | 24·00 | 300·15 |
| 26 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 11·30 | 311·45 |

Resistance Cold, 98. Discoloration, 2½.

## *White Lamp, No. 3.*

(Reduction Factor, 0·85.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 50·00 | ·928 | 46·40 | 10·75 | 9·09 | 4·05 | 11·08 | 53·88 | 0·45 | 0·45 |
| 13 | 49·95 | ·949 | 47·40 | 13·5 | 11·5 | ........... | 14·0 | 52·63 | 10·45 | 11·30 |
| 14 | 49·75 | ·969 | 48·20 | 15·2 | 12·9 | ........... | 15·7 | 51·34 | 24·00 | 35·30 |
| *15 | 50·15 | ·989 | 49·59 | 18·2 | 15·5 | ........... | 18·9 | 50·71 | 24·00 | 59·30 |
| 16 | 49·90 | ·992 | 49·50 | 16·6 | 14·1 | ........... | 17·2 | 50·30 | 24·00 | 83·30 |
| 17 | 49·95 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 107·30 |
| 18 | 50·00 | 1·001 | 50·05 | 16·8 | 14·3 | ........... | 17·4 | 49·95 | 24·00 | 131·30 |
| 19 | 50 05 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 155·30 |
| 20 | 49·85 | ·998 | 49·75 | 16·4 | 13·9 | ........... | 17·0 | 49·95 | 24·00 | 179·30 |
| 21 | 50·05 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 203·30 |
| 22 | 49·95 | ·997 | 49·80 | 15·8 | 13·4 | ........... | 16·3 | 50·10 | 24·00 | 227·30 |
| 23 | 50·05 | ·996 | 49·84 | 14·4 | 12·2 | ........... | 14·9 | 50·25 | 24·00 | 251·30 |
| 24 | 50·10 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 275·30 |
| *25 | 49·95 | ·988 | 49·35 | 11·6 | 9·9 | ........... | 12·1 | 50·56 | 24·00 | 299·30 |
| 26 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 11·30 | 311·00 |

Resistance Cold, 105. Discoloration, 3.

## *White Lamp, No. 4.*

(Reduction Factor, 0·85.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 49·95 | 1·020 | 50·95 | 16·75 | 14·17 | 3·59 | 17·17 | 48·97 | 0·15 | 0·15 |
| 13 | 49·90 | 1·054 | 52·59 | 20·2 | 17·2 | ........... | 20·8 | 47·34 | 11·30 | 11·45 |
| 14 | 49·75 | 1·079 | 53·68 | 21·8 | 18·5 | ........... | 22·4 | 46·11 | 24·00 | 35·45 |
| *15 | 50·05 | 1·087 | 54·40 | 24·0 | 20·4 | ........... | 24·7 | 46·04 | 24·00 | 59·45 |
| 16 | 50·00 | 1·087 | 54·35 | 22·3 | 19·0 | ........... | 23·0 | 46·00 | 24·00 | 83·45 |
| 17 | 50·20 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 107·45 |
| 18 | 50·50 | 1·094 | 55·24 | 21·8 | 18·5 | ........... | 22·4 | 46·16 | 24·00 | 131·45 |
| 19 | 50·35 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 155·45 |
| 20 | 50·10 | 1·079 | 54·05 | 19·4 | 16·5 | ........... | 20·0 | 46·43 | 24·00 | 179·45 |
| 21 | 50·25 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 203·45 |
| 22 | 50·10 | 1·068 | 53·50 | 18·6 | 15·8 | ........... | 19·1 | 46·91 | 24·00 | 227·45 |
| 23 | 50·20 | 1·072 | 53·81 | 17·5 | 14·9 | ........... | 18·0 | 46·83 | 24·00 | 251·45 |
| 24 | 50·10 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 275·45 |
| *25 | 49·95 | 1·054 | 52·64 | 13·2 | 11·2 | ........... | 13·6 | 47·39 | 24·00 | 299·45 |
| 26 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 11·30 | 311·15 |

Resistance Cold, 99. Discoloration, 3.

## *White Lamp, No. 5.*

(Reduction Factor, 0·84.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 50·00 | ·995 | 49·75 | 17·00 | 14·31 | 3·47 | 17·05 | 50·25 | 0·30 | 0·30 |
| 13 | 49·95 | 1·025 | 51·19 | 20·0 | 16·8 | ........... | 20·00 | 48·73 | 10·30 | 11·00 |
| 14 | 49·90 | 1·056 | 52·69 | 22·0 | 18·5 | ........... | 22·00 | 47·25 | 24·00 | 35·00 |
| *15 | 49·70 | 1·056 | 52·48 | 23·9 | 20·1 | ........... | 23·9 | 47·07 | 24·00 | 59·00 |
| 16 | 49·70 | 1·058 | 52·58 | 22·2 | 18·6 | ........... | 22·2 | 46·98 | 24·00 | 83·00 |
| 17 | 49·95 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 107·00 |
| 18 | 49·80 | 1·054 | 52·48 | 20·2 | 17·0 | ........... | 20·2 | 47·25 | 24·00 | 131·00 |
| 19 | 50·10 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 155·00 |
| 20 | 50·05 | 1·044 | 52·25 | 17·6 | 14·8 | ........... | 17·6 | 47·94 | 24·00 | 179·00 |
| 21 | 50·00 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 203·00 |
| 22 | 49·90 | 1·033 | 51·54 | 15·9 | 13·4 | ........... | 16·0 | 48·30 | 24·00 | 227·00 |
| 23 | 50·10 | 1·031 | 51·65 | 14·5 | 12·2 | ........... | 14·5 | 48·59 | 24·00 | 251·00 |
| 24 | 50·35 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 275·00 |
| *25 | 50·10 | 1·023 | 51·25 | 11·3 | 9·5 | ........... | 11·3 | 48·97 | 24·00 | 299·00 |
| 26 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 11·30 | 310·30 |

Resistance Cold, 103. Discoloration, 4.

## *White Lamp, No. 6.*

(Reduction Factor, 0·84.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 50·00 | 1·047 | 52·35 | 17·38 | 14·64 | 3·57 | 17·55 | 47·76 | 0·15 | 0·15 |
| 13 | 49·65 | 1·070 | 53·12 | 20·3 | 17·1 | ........... | 20·5 | 46·40 | 10·15 | 10·30 |
| 14 | 49·90 | 1·098 | 54·79 | 22·3 | 18·7 | ........... | 22·4 | 45·45 | 24·00 | 34·30 |
| *15 | 50·20 | 1·113 | 55·87 | 27·1 | 22·8 | ........... | 27·4 | 45·10 | 24·00 | 58·30 |
| 16 | 50·25 | 1·116 | 56·07 | 25·5 | 21·4 | ........... | 25·7 | 45·03 | 24·00 | 82·30 |
| 17 | 49·95 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 106·30 |
| 18 | 49·80 | 1·093 | 54·43 | 22·0 | 18·5 | ........... | 22·2 | 45·56 | 24·00 | 130·30 |
| 19 | 50·05 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 154·30 |
| 20 | 49·95 | 1·086 | 54·24 | 19·5 | 16·4 | ........... | 19·7 | 46·00 | 24·00 | 178·30 |
| 21 | 50·10 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 202·30 |
| 22 | 50·10 | 1·073 | 53·75 | 18·5 | 15·5 | ........... | 18·6 | 46·69 | 24·00 | 226·30 |
| 23 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 2·00 | 228·30 |

Carbon broke at side of loop 2 A.M., May 23, 1885. Discoloration, 4.

## *White Lamp, No. 7.*

(Reduction Factor, 0·85.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 50·00 | 1·001 | 50·05 | 16·46 | 13·99 | 3·57 | 16·98 | 49·95 | 0·30 | 0·30 |
| 13 | 50·35 | 1·033 | 52·01 | 20·2 | 17·2 | ........... | 21·8 | 48·74 | 11·45 | 11·45 |
| 14 | 50·20 | 1·043 | 52·35 | 21·9 | 18·6 | ........... | 22·5 | 48·13 | 24·00 | 35·45 |
| *15 | 50·00 | 1·038 | 51·90 | 23·8 | 20·2 | ........... | 24·4 | 48·17 | 24·00 | 59·45 |
| 16 | 50·20 | 1·040 | 52·20 | 20·1 | 17·1 | ........... | 20·7 | 48·27 | 24·00 | 83·45 |
| 17 | 49·95 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 107·45 |
| 18 | 49·75 | 1·019 | 50·69 | 18·0 | 15·3 | ........... | 18·5 | 48·82 | 24·00 | 131·45 |
| 19 | 50·20 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 155·45 |
| 20 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 4·00 | 159·45 |

Carbon broke at side of loop 4 A.M., May 20, 1885. Discoloration, 3½.

## *White Lamp, No. 8.*

(Reduction Factor, 0·83.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 50·00 | 1·025 | 51·25 | 14·3 | 11·69 | 4·38 | 14·23 | 48·78 | 0·15 | 0·15 |
| 13 | 49·70 | 1·030 | 51·19 | 15·2 | 12·6 | ........... | 15·4 | 48·25 | 10·00 | 10·15 |
| 14 | 49·95 | 1·056 | 52·74 | 17·9 | 14·9 | ........... | 18·2 | 47·30 | 24·00 | 34·15 |
| *15 | 50·15 | 1·071 | 53·71 | 20·5 | 17·0 | ........... | 20·7 | 46·83 | 24·00 | 58·15 |
| 16 | 49·90 | 1·073 | 53·54 | 19·6 | 16·3 | ........... | 19·9 | 46·51 | 24·00 | 82·15 |
| 17 | 50·00 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 106·15 |
| 18 | 49·95 | 1·080 | 53·94 | 19·4 | 16·1 | ........... | 19·6 | 46·25 | 24·00 | 130·15 |
| 19 | 50·15 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 154·15 |
| 20 | 49·75 | 1·076 | 53·53 | 18·3 | 15·2 | ........... | 18·5 | 46·24 | 24·00 | 178·15 |
| 21 | 50·05 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 202·15 |
| 22 | 49·85 | 1·075 | 53·59 | 18·4 | 15·3 | ........... | 18·7 | 46·37 | 24·00 | 226·15 |
| 23 | 49·90 | 1·075 | 53·64 | 15·8 | 13·1 | ........... | 16·0 | 46·42 | 24·00 | 250·15 |
| 24 | 50·00 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 274·15 |
| *25 | 50·05 | 1·077 | 53·90 | 13·5 | 11·2 | ........... | 13·7 | 46·47 | 24·00 | 298·15 |
| 26 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 11·30 | 309·45 |

Resistance Cold, 97. Discoloration, 3.

## *White Lamp, No. 9.*

(Reduction Factor, 0·83.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 50·00 | 1·206 | 60·30 | 15·95 | 13·22 | 4·56 | 15·92 | 41·46 | 0·30 | 0·30 |
| 13 | 50·00 | 1·214 | 60·70 | 18·1 | 15·0 | ........... | 18·0 | 41·19 | 11·00 | 11·30 |
| 14 | 50·20 | 1·227 | 61·59 | 19·9 | 16·5 | ........... | 19·8 | 40·91 | 24·00 | 35·30 |
| *15 | 49·95 | 1·224 | 61·13 | 19·7 | 16·4 | ........... | 19·7 | 40·81 | 24·00 | 59·30 |
| 16 | 49·95 | ........... | ........... | 19·5 | 16·2 | ........... | 19·4 | ........... | 24·00 | 83·30 |
| 17 | 50·25 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 107·30 |
| 18 | 49·80 | 1·222 | 60·85 | 18·4 | 15·3 | ........... | 18·4 | 40·75 | 24·00 | 131·30 |
| 19 | 50·10 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 155·30 |
| 20 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 9·30 | 165·00 |

Carbon broke at middle of loop 9.25 A. M., May 20, 1885. Discoloration, 2½.

## *White Lamp, No. 10.*

(Reduction Factor, 0·81.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 49·95 | ·908 | 45·35 | 14·20 | 11·55 | 3·92 | 14·26 | 55·01 | 0·15 | 0·15 |
| 13 | 49·95 | ·914 | 45·65 | 16·4 | 13·3 | ........... | 16·4 | 54·65 | 10·00 | 10·15 |
| 14 | 49·65 | ·924 | 45·87 | 17·3 | 14·0 | ........... | 11·2 | 53·73 | 24·00 | 34·15 |
| *15 | 50·05 | ·935 | 46·79 | 19·9 | 16·1 | ........... | 19·8 | 53·53 | 24·00 | 58·15 |
| 16 | 49·90 | ·931 | 46·45 | 18·2 | 14·7 | ........... | 18·1 | 53·60 | 24·00 | 82·15 |
| 17 | 50·20 | ........... | ........... | ........... | ........... | ........... | | ........... | 24·00 | 106·15 |
| 18 | 49·85 | ·931 | 46·41 | 18·3 | 14·8 | ........... | 18·2 | 53·55 | 24·00 | 130·15 |
| 19 | 50·10 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 154·15 |
| 20 | 49·95 | ·928 | 46·35 | 17·0 | 13·8 | ........... | 17·0 | 53·83 | 24·00 | 178·15 |
| 21 | 50·10 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 202·15 |
| 22 | 50·10 | ·921 | 46·14 | 16·9 | 13·7 | ........... | 16·9 | 54·40 | 24·00 | 226·15 |
| 23 | 50·20 | ·922 | 46·28 | 14·3 | 11·6 | ........... | 14·3 | 54·45 | 24·00 | 250·15 |
| 24 | 50·00 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 274·15 |
| *25 | 50·10 | ·915 | 45·84 | 11·1 | 9·0 | ........... | 11·1 | 54·76 | 24·00 | 298·15 |
| 26 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 11·30 | 309·45 |

Resistance Cold, 114. Discoloration, 3.

## Weston Lamps, 110½ Volts.

### *Weston Lamp, No. 1.*

(Reduction Factor, 0·87.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 111·3 | ·519 | 57·76 | 20·10 | 17·49 | 3·30 | 19·36 | 214·5 | 1·45 | 1·45 |
| 11 | .......... | .......... | .......... | 17·5 | 15·2 | .......... | 16·9 | .......... | 3·45 | 5·30 |
| 12 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 29·30 |
| 13 | 108·4 | ·458 | 49·65 | 10·1 | 8·8 | .......... | 9·8 | 236·7 | 24·00 | 53·30 |
| 14 | 109·8 | ·458 | 50·29 | 11·5 | 10·0 | .......... | 11·1 | 239·7 | 24·00 | 77·30 |
| 15 | 110·6 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 101·30 |
| 16 | 110·5 | ·460 | 50·83 | 13·6 | 11·9 | .......... | 13·2 | 240·2 | 24·00 | 125·30 |
| 17 | 110·2 | ·455 | 50·14 | 12·1 | 10·5 | .......... | 11·7 | 242·2 | 24·00 | 149·30 |
| 18 | 111·3 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 173·30 |
| 19 | 110·9 | ·458 | 50·79 | 12·7 | 11·0 | .......... | 12·2 | 242·1 | 24·00 | 197·30 |
| 20 | 110·6 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 20·45 | 218·15 |
| 21 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 9·00 | 227·15 |

Carbon broke at side of loop 9.00 A. M., April 21. 1885. Discoloration, 2½

### *Weston Lamp, No. 2.*

(Reduction Factor, 0·85.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 111·0 | ·530 | 58·83 | 16·72 | 14·16 | 4·15 | 15·37 | 209·4 | 2·15 | 2·15 |
| 11 | .......... | .......... | .......... | 16·2 | 13·8 | .......... | 15·0 | .......... | 3·45 | 6·00 |
| 12 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 30·00 |
| 13 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 16·45 | 46·45 |

Carbon broke at side of loop at 4.45 P. M., April, 13, 1885. Discoloration, ½.

## *Weston Lamp, No. 3.*

(Reduction Factor, 0·87.)

| Date. | Volts. | Amperes. | Watts. | Candles. | | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Observed. | Spherical. | | | | | |
| 1885. April. | 111·3 | ·502 | 55·87 | 16·32 | 14·28 | 3·82 | 15·77 | 221·7 | 1·00 | 1·00 |
| 11 | ... | ... | ... | 14·0 | 12·2 | ... | 13·4 | ... | 3·45 | 4·45 |
| 12 | ... | ... | ... | ... | ... | ... | ... | ... | 24·00 | 28·45 |
| 13 | 108·3 | ·435 | 47·11 | 4·9 | 4·3 | ... | 4·7 | 249·0 | 24·00 | 52·45 |
| 14 | 111·3 | ·451 | 50·19 | 6·7 | 5·8 | ... | 6·4 | 246·8 | 24·00 | 76·45 |
| 15 | 110·6 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 100·45 |
| 16 | 110·6 | ·444 | 49·10 | 3·5 | 3·0 | ... | 3·3 | 249·1 | 24·00 | 124·45 |
| 17 | 110·3 | ·446 | 49·19 | 6·5 | 5·7 | ... | 6·3 | 247·3 | 24·00 | 148·45 |
| 18 | 111·4 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 172·45 |
| 19 | 110·9 | ·449 | 49·79 | 6·7 | 5·8 | ... | 6·4 | 247·0 | 24·00 | 196·45 |
| 20 | 109·6 | ... | ... | ... | ... | ... | ... | ... | 20·45 | 217·30 |
| 21 | 110·0 | ·445 | 48·95 | 6·8 | 5·9 | ... | 6·5 | 247·2 | 24·00 | 241·30 |
| 22 | 110·0 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 265·30 |
| 23 | 110·5 | ·446 | 49·28 | 6·1 | 5·3 | ... | 5·8 | 247·8 | 24·00 | 289·30 |
| 24 | 110·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 313·30 |
| *25 | 110·4 | ·446 | 49·23 | 6·1 | 5·3 | ... | 5·8 | 247·5 | 24·00 | 337·30 |
| 26 | 110·1 | ... | ... | ... | ... | ... | ... | ... | 21·00 | 358·30 |
| *27 | 110·0 | ·444 | 48·83 | 6·4 | 5·6 | ... | 6·2 | 247·7 | 24·00 | 382·30 |
| *28 | 110·4 | ·448 | 49·46 | 5·9 | 5·1 | ... | 5·6 | 246·4 | 24·00 | 406·30 |
| *29 | 110·6 | ·448 | 49·55 | 5·9 | 5·1 | ... | 5·6 | 246·9 | 24·00 | 430·30 |
| 30 | 110·4 | ·451 | 49·79 | 7·9 | 6·9 | ... | 7·6 | 244·8 | 24·00 | 454·30 |
| May. | | | | | | | | | | |
| 1 | 110·3 | ·448 | 49·41 | 7·5 | 6·5 | ... | 7·2 | 246·2 | 24·00 | 478·30 |
| 2 | 110·3 | ·448 | 49·41 | 7·0 | 6·1 | ... | 6·7 | 246·2 | 24·00 | 502·30 |
| 3 | 110·7 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 526·30 |
| 4 | 110·3 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 550·30 |
| 5 | 110·5 | ·451 | 49·83 | 7·8 | 6·8 | ... | 7·5 | 245·0 | 24·00 | 574·30 |
| 6 | 110·4 | ·448 | 49·46 | 7·7 | 6·7 | ... | 7·4 | 246·4 | 23·30 | 598·00 |
| 7 | 110·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 622·00 |
| 8 | 110·4 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 646·00 |
| 9 | 110·1 | ·447 | 49·21 | 8·0 | 7·0 | ... | 7·7 | 246·3 | 24·00 | 670·00 |
| 10 | 110·4 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 694·00 |
| 11 | 110·4 | ·450 | 49·68 | 7·8 | 6·8 | ... | 7·5 | 245·3 | 24·00 | 718·00 |
| 12 | 110·4 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 742·00 |
| 13 | 110·8 | ... | ... | ... | ... | ... | ... | ... | 23·30 | 765·30 |
| 14 | 110·6 | ·450 | 49·77 | 7·9 | 6·9 | ... | 7·6 | 245·8 | 24·00 | 789·30 |
| 15 | 110·7 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 813·30 |
| 16 | 110·1 | ·449 | 49·43 | 7·9 | 6·9 | ... | 7·6 | 245·2 | 24·00 | 837·30 |
| 17 | 110·6 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 861·30 |
| 18 | 110·3 | ·450 | 49·63 | 8·5 | 7·4 | ... | 8·1 | 245·1 | 24·00 | 885·30 |
| 19 | 110·2 | ·452 | 49·81 | 7·3 | 6·4 | ... | 7·0 | 243·8 | 24·00 | 909·30 |
| 20 | 110·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 933·30 |
| 21 | 110·3 | ·450 | 49·63 | 7·9 | 6·9 | ... | 7·6 | 245·1 | 24·00 | 957·30 |
| 22 | 110·3 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 981·30 |
| 23 | 109·9 | ·448 | 49·23 | 7·7 | 6·7 | ... | 7·4 | 245·3 | 24·00 | 1,005·30 |
| 24 | 110·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 1,029·30 |
| *25 | 109·9 | ·449 | 49·34 | 6·0 | 5·2 | ... | 5·7 | 244·8 | 24·00 | 1,053·30 |
| 26 | ... | ... | ... | ... | ... | ... | ... | ... | 11·30 | 1,065·00 |

Resistance Cold, 442. Discoloration 2.

## *Weston Lamp, No. 4.*

(Reduction Factor, 0·78.)

| Date. | Volts. | Amperes. | Watts | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 111·6 | ·546 | 60·93 | 16·20 | 12·70 | 4·79 | 13·81 | 204·4 | 1·30 | 1·30 |
| 11 | ........ | ........ | ........ | 11·1 | 8·7 | ........ | 9·5 | ........ | 3·45 | 5·15 |
| 12 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 29·15 |
| 13 | 108·4 | ·452 | 49·09 | 4·3 | 3·4 | ........ | 3·7 | 239·8 | 24·00 | 53·15 |
| 14 | 110·5 | ·447 | 49·39 | 4·9 | 3·8 | ........ | 4·1 | 247·2 | 24·00 | 77·15 |
| 15 | 110·6 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 101·15 |
| 16 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 5·30 | 106·45 |

Carbon broke at side of loop 5.30 A. M., April 16, 1885. Discoloration, 1½.

## *Weston Lamp, No. 5.*

(Reduction Factor, 0·88.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 111·5 | ·537 | 59·87 | 18·18 | 16·01 | 3·74 | 17·53 | 207·6 | 0·30 | 0·30 |
| 11 | ........ | ........ | ........ | 16·6 | 14·6 | ........ | 15·9 | ........ | 3·45 | 4·15 |
| 12 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 28·15 |
| 13 | 108·2 | ·492 | 53·23 | 11·0 | 9·7 | ........ | 10·6 | 219·9 | 24·00 | 52·15 |
| 14 | 109·3 | ·496 | 54·21 | 12·2 | 10·7 | ........ | 11·7 | 220·4 | 24·00 | 76·15 |
| 15 | 110·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 100·15 |
| 16 | 110·6 | ·499 | 55·19 | 14·5 | 12·8 | ........ | 14·0 | 221·6 | 24·00 | 124·15 |
| 17 | 110·4 | ·498 | 54·98 | 12·6 | 11·1 | ........ | 12·1 | 221·7 | 24·00 | 148·15 |
| 18 | 111·5 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 172·15 |
| 19 | 111·3 | ·500 | 55·65 | 13·8 | 12·1 | ........ | 13·2 | 222·6 | 24·00 | 196·15 |
| 20 | 111·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 20·45 | 217·00 |
| 21 | 110·1 | ·491 | 54·05 | 13·6 | 12·0 | ........ | 13·1 | 224·2 | 24·00 | 241·00 |
| 22 | 109·8 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 265·00 |
| 23 | 110·1 | ·484 | 53·28 | 11·6 | 10·2 | ........ | 11·1 | 227·5 | 24·00 | 289·00 |
| 24 | 110·4 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 313·00 |
| 25 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 7·00 | 320·00 |

Carbon broke at middle of loop 7.00 A. M., April 25, 1885. Discoloration, 2½.

## *Weston Lamp, No. 6.*

(Reduction Factor, 0·81. Resistance Cold, 402.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 111·5 | ·501 | 55·86 | 14·00 | 11·25 | 4·96 | 12·18 | 222·6 | 1·15 | 1·15 |
| 11 | ...... | ...... | ...... | 13·0 | 10·5 | ...... | 11·3 | ...... | 3·45 | 5·00 |
| 12 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 29·00 |
| 13 | 108·7 | ·476 | 51·74 | 9·1 | 7·4 | ...... | 8·0 | 228·4 | 24·00 | 53·00 |
| 14 | 109·1 | ·480 | 52·37 | 9·6 | 7·8 | ...... | 8·4 | 227·3 | 24·00 | 77·00 |
| 15 | 110·6 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 101·00 |
| 16 | 110·9 | ·490 | 54·34 | 11·6 | 9·4 | ...... | 10·2 | 226·3 | 24·00 | 125·00 |
| 17 | 110·3 | ·492 | 54·26 | 11·1 | 9·0 | ...... | 9·7 | 224·2 | 24·00 | 149·00 |
| 18 | 111·3 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 173·00 |
| 19 | 111·5 | ·499 | 55·63 | 11·1 | 9·0 | ...... | 9·7 | 223·4 | 24·00 | 197·00 |
| 20 | 111·4 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 20·45 | 217·45 |
| 21 | 110·0 | ·491 | 54·01 | 11·7 | 9·5 | ...... | 10·3 | 224·0 | 24·00 | 241·45 |
| 22 | 109·7 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 265·45 |
| 23 | 110·8 | ·498 | 55·17 | 10·8 | 8·7 | ...... | 9·4 | 222·5 | 24·00 | 289·45 |
| 24 | 110·7 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 313·45 |
| *25 | 110·9 | ·500 | 55·44 | 10·8 | 8·7 | ...... | 9·4 | 221·8 | 24·00 | 337·45 |
| 26 | 110·6 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 21·00 | 358·45 |
| *27 | 110·4 | ·496 | 54·75 | 10·8 | 8·7 | ...... | 9·4 | 222·6 | 24·00 | 382·45 |
| *28 | 110·3 | ·494 | 54·48 | 10·1 | 8·2 | ...... | 8·9 | 223·3 | 24·00 | 406·45 |
| *29 | 110·4 | ·497 | 54·87 | 10·0 | 8·1 | ...... | 8·7 | 222·1 | 24·00 | 430·45 |
| 30 | 110·4 | ·499 | 55·09 | 13·6 | 11·8 | ...... | 11·9 | 221·2 | 24·00 | 454·45 |
| May. | | | | | | | | | | |
| 1 | 110·5 | ·497 | 54·91 | 12·3 | 10·0 | ...... | 10·8 | 222·3 | 24·00 | 478·45 |
| 2 | 110·4 | ·498 | 54·98 | 12·6 | 10·2 | ...... | 11·0 | 221·7 | 24·00 | 502·45 |
| 3 | 110·2 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 526·45 |
| 4 | 110·2 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 550·45 |
| 5 | 110·5 | ·496 | 54·80 | 13·0 | 10·5 | ...... | 11·3 | 222·8 | 24·00 | 574·45 |
| 6 | 110·2 | ·496 | 54·65 | 12·3 | 10·0 | ...... | 10·8 | 222·2 | 23·30 | 598·15 |
| 7 | 110·1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 622·15 |
| 8 | 110·4 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 646·15 |
| 9 | 109·9 | ·494 | 54·29 | 12·5 | 10·1 | ...... | 10·9 | 222·5 | 24·00 | 670·15 |
| 10 | 110·1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 694·15 |
| 11 | 110·7 | ·498 | 55·12 | 12·7 | 10·3 | ...... | 11·1 | 222·3 | 24·00 | 718·15 |
| 12 | 110·4 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 742·15 |
| 13 | 111·1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 23·30 | 765·45 |
| 14 | 110·7 | ·499 | 55·24 | 12·4 | 10·0 | ...... | 10·8 | 221·8 | 24·00 | 789·45 |
| 15 | 110·9 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 813·45 |
| 16 | 110·8 | ·502 | 55·62 | 13·4 | 10·9 | ...... | 11·8 | 220·7 | 24·00 | 837·45 |
| 17 | 110·8 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 861·45 |
| 18 | 110·9 | ·499 | 55·33 | 13·7 | 11·1 | ...... | 12·0 | 222·2 | 24·00 | 885·45 |
| 19 | 110·9 | ·498 | 55·22 | 11·7 | 9·5 | ...... | 10·3 | 222·7 | 24·00 | 909·45 |
| 20 | 110·9 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 933·45 |
| 21 | 110·9 | ·499 | 55·33 | 13·1 | 10·6 | ...... | 11·4 | 222·2 | 24·00 | 957·45 |
| 22 | 110·9 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 981·45 |
| 23 | 110·6 | ·495 | 54·74 | 12·4 | 10·0 | ...... | 10·8 | 223·4 | 24·00 | 1,005·45 |
| 24 | 110·7 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 1,029·45 |
| *25 | 110·6 | ·494 | 54·63 | 9·7 | 7·9 | ...... | 8·5 | 223·9 | 24·00 | 1,053·45 |
| 26 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 11·30 | 1,065·15 |

Resistance Cold, 424. Discoloration, 2.

## *Weston Lamp, No. 7.*

(Reduction Factor, 0·83. Resistance Cold, 414.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 111·5 | ·543 | 60·54 | 21·95 | 18·32 | 3·30 | 20·10 | 205·8 | 0·30 | 0·30 |
| 11 | ........ | ........ | ........ | 14·0 | 11·6 | ........ | 12·8 | ........ | 3·45 | 4·15 |
| 12 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 28·15 |
| 13 | 109·0 | ·432 | 47·09 | 3·8 | 3·2 | ........ | 3·5 | 252·3 | 24·00 | 52·15 |
| 14 | 109·3 | ·421 | 46·01 | 3·6 | 3·0 | ........ | 3·3 | 259·6 | 24·00 | 76·15 |
| 15 | 110·8 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 100·15 |
| 16 | 111·2 | ·412 | 45·81 | 2·1 | 1·8 | ........ | 2·0 | 269·9 | 24·00 | 124·15 |
| 17 | 110·7 | ·406 | 44·94 | 3·6 | 3·0 | ........ | 3·3 | 272·7 | 24·00 | 148·15 |
| 18 | 111·3 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 172·15 |
| 19 | 112·2 | ·401 | 44·99 | 3·8 | 3·2 | ........ | 3·5 | 279·8 | 24·00 | 196·15 |
| 20 | 112·4 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 20·45 | 217·00 |
| 21 | 110·7 | ·392 | 43·39 | 3·7 | 3·1 | ........ | 3·4 | 282·4 | 24·00 | 241·00 |
| 22 | 110·4 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 265·00 |
| 23 | 110·7 | ·391 | 43·28 | 3·3 | 2·7 | ........ | 3·0 | 283·1 | 24·00 | 289·00 |
| 24 | 110·7 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 313·00 |
| *25 | 110·6 | ·390 | 43·13 | 3·2 | 2·7 | ........ | 3·0 | 283·6 | 24·00 | 337·00 |
| 26 | 110·1 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 21·00 | 358·00 |
| *27 | 110·5 | ·384 | 42·43 | 3·4 | 2·8 | ........ | 3·1 | 287·8 | 24·00 | 382·00 |
| *28 | 110·8 | ·387 | 42·88 | 3·0 | 2·5 | ........ | 2·8 | 286·3 | 24·00 | 406·00 |
| *29 | 110·5 | ·385 | 42·54 | 2·9 | 2·4 | ........ | 2·6 | 287·0 | 24·00 | 430·00 |
| 30 | 111·0 | ·387 | 42·95 | 4·6 | 3·8 | ........ | 4·2 | 286·8 | 24·00 | 454·00 |
| May. | | | | | | | | | | |
| 1 | 110·7 | ·388 | 42·95 | 3·8 | 3·2 | ........ | 3·5 | 285·3 | 24·00 | 478·00 |
| 2 | 110·6 | ·387 | 42·80 | 3·7 | 3·1 | ........ | 3·4 | 285·8 | 24·00 | 502·00 |
| 3 | 110·5 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 526·00 |
| 4 | 111·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 550·00 |
| 5 | 111·0 | ·389 | 43·17 | 4·2 | 3·5 | ........ | 3·9 | 285·3 | 24·00 | 574·00 |
| 6 | 110·0 | ·383 | 42·13 | 3·7 | 3·1 | ........ | 3·4 | 287·2 | 23·30 | 597·30 |
| 7 | 110·4 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 621·30 |
| 8 | 110·7 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 645·30 |
| 9 | 110·2 | ·382 | 42·09 | 4·0 | 3·3 | ........ | 3·6 | 288·5 | 24·00 | 669·30 |
| 10 | 110·5 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 693·30 |
| 11 | 110·5 | ·382 | 42·21 | 3·8 | 3·2 | ........ | 3·5 | 289·3 | 24·00 | 717·30 |
| 12 | 110·4 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 741·30 |
| 13 | 111·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 23·30 | 765·00 |
| 14 | 110·6 | ·385 | 42·58 | 3·8 | 3·2 | ........ | 3·5 | 287·3 | 24·00 | 789·00 |
| 15 | 111·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 813·00 |
| 16 | 110·3 | ·383 | 42·24 | 4·2 | 3·5 | ........ | 3·9 | 288·0 | 24·00 | 837·00 |
| 17 | 110·7 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 861·00 |
| 18 | 110·4 | ·382 | 42·17 | 4·1 | 3·4 | ........ | 3·7 | 289·0 | 24·00 | 885·00 |
| 19 | 110·4 | ·382 | 42·17 | 3·5 | 2·9 | ........ | 3·2 | 289·0 | 24·00 | 909·00 |
| 20 | 110·4 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 933·00 |
| 21 | 110·4 | ·379 | 41·84 | 3·9 | 3·2 | ........ | 3·5 | 291·3 | 24·00 | 957·00 |
| 22 | 110·6 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 981·00 |
| 23 | 110·2 | ·379 | 41·76 | 3·5 | 2·9 | ........ | 3·2 | 290·8 | 24·00 | 1,005·00 |
| 24 | 110·6 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 1,029·00 |
| *25 | 110·5 | ·379 | 41·87 | 2·7 | 2·2 | ........ | 2·4 | 291·6 | 24·00 | 1,053·00 |
| 26 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 11·30 | 1,064·30 |

Resistance Cold, 544. Discoloration, 2.

## *Weston Lamp, No. 8.*

(Reduction Factor, 0·92. Resistance Cold, 423.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885 April. | 111·5 | ·523 | 58·31 | 21·88 | 20·23 | 2·88 | 22·54 | 213·2 | 0·30 | 0·30 |
| 11 | ........... | ........... | ........... | 19·5 | 17·9 | ........... | 19·9 | ........... | 3·45 | 4·15 |
| 12 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ... ... ... | 24·00 | 28·15 |
| 13 | 110·0 | ·458 | 50·38 | 10·9 | 10·0 | ........... | 11·1 | 240·2 | 24·00 | 52·15 |
| 14 | 109·9 | ·454 | 49·89 | 10·9 | 10·0 | ........... | 11·1 | 242·1 | 24·00 | 76·15 |
| 15 | 111·0 | ........... | ........... | ........... | ........... | ........... | ........... | ........ ... | 24·00 | 100·15 |
| 16 | 112·3 | ·458 | 51·43 | 13·0 | 11·9 | ........... | 13·2 | 245·2 | 24·00 | 124·15 |
| 17 | 110·7 | ·449 | 49·70 | 11·1 | 10·2 | ........... | 11·3 | 246·5 | 17·00 | 141·15 |

Carbon broke at both shanks 5.00 P. M., April 17, 1885. Discoloration, 2½.

## *Weston Lamp, No. 11.*

(Reduction Factor, 0·77. Resistance Cold, 409.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 111·4 | ·513 | 57·14 | 21·04 | 16·16 | 3·53 | 17·86 | 217·2 | 0·30 | 0·30 |
| 11 | ........... | ........... | ........... | 14·2 | 10·9 | ........... | 12·1 | ........... | 3·45 | 4·15 |
| 12 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 28·15 |
| 13 | 110·1 | ·430 | 47·34 | 5·1 | 3·9 | ........... | 4·3 | 256·0 | 24·00 | 52·15 |
| 14 | 110·6 | ·428 | 47·33 | 4·7 | 3·6 | ........... | 4·0 | 258·4 | 24·00 | 76·15 |
| 15 | 111·7 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 100·15 |
| 16 | 111·7 | ·413 | 46·13 | 2·6 | 2·0 | ........... | 2·2 | 270·5 | 24·00 | 124·15 |
| 17 | 110·7 | ·403 | 44·61 | 3·6 | 2·8 | ........... | 3·1 | 274·7 | 24·00 | 148·15 |
| 18 | 110·5 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 21·00 | 169·15 |

Carbon broke at middle of loop 9.00 P. M., April 18, 1885. Discoloration, 1½.

## *Weston Lamp, No. 9.*

(Reduction Factor, 0·75. Resistance Cold, 409.

| Date. | Volts. | Amperes | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Mean Horizontal Candles. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 111·4 | ·530 | 59·04 | 21·90 | 16·53 | 3·57 | 17·97 | 210·2 | 0·30 | 0·30 |
| 11 | ... | ... | ... | 15·0 | 11·3 | ... | 12·3 | ... | 3·45 | 4·15 |
| 12 | ... | ... | ... | ... | ... | ... | ... | ... | 24·00 | 28·15 |
| 13 | 110·5 | ·457 | 50·50 | 7·0 | 5·3 | ... | 5·8 | 241·8 | 24·00 | 52·15 |
| 14 | 110·1 | ·455 | 50·09 | 7·5 | 5·7 | ... | 6·2 | 242·0 | 24·00 | 76·15 |
| 15 | 110·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 100·15 |
| 16 | 112·1 | ·467 | 52·35 | 9·6 | 7·2 | ... | 7·8 | 240·0 | 24·00 | 124·15 |
| 17 | 110·9 | ·460 | 51·01 | 8·1 | 6·1 | ... | 6·6 | 241·1 | 24·00 | 148·15 |
| 17 | 110·8 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 172·15 |
| 19 | 111·7 | ·462 | 51·60 | 8·3 | 6·2 | ... | 6·8 | 241·8 | 24·00 | 196·15 |
| 20 | 111·4 | ... | ... | ... | ... | ... | ... | ... | 20·45 | 217·00 |
| 21 | 109·8 | ·456 | 50·06 | 8·2 | 6·2 | ... | 6·8 | 240·8 | 24·00 | 241·00 |
| 22 | 109·7 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 265·00 |
| 23 | 110·2 | ·453 | 49·92 | 7·4 | 5·6 | ... | 6·1 | 243·3 | 24·00 | 289·00 |
| 24 | 110·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 313·00 |
| *25 | 110·5 | ·456 | 50·38 | 7·4 | 5·6 | ... | 6·1 | 242·3 | 24·00 | 337·00 |
| 26 | 110·2 | ... | ... | ... | ... | ... | ... | ... | 21·00 | 358·00 |
| *27 | 109·7 | ·454 | 49·80 | 7·4 | 5·6 | ... | 6·1 | 241·6 | 24·00 | 382·00 |
| *28 | 110·7 | ·456 | 50·47 | 6·9 | 5·2 | ... | 5·7 | 242·8 | 24·00 | 406·00 |
| *29 | 110·4 | ·457 | 50·45 | 7·1 | 5·3 | ... | 5·8 | 241·6 | 24·00 | 430·00 |
| 30 | 110·3 | ·456 | 50·29 | 10·2 | 7·7 | ... | 8·4 | 241·9 | 24·00 | 454·00 |
| May. | | | | | | | | | | |
| 1 | 110·4 | ·455 | 50·23 | 8·5 | 6·4 | ... | 7·0 | 242·6 | 24·00 | 478·00 |
| 2 | 110·3 | ·457 | 50·40 | 8·5 | 6·4 | ... | 7·0 | 241·4 | 24·00 | 502·00 |
| 3 | 110·6 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 526·00 |
| 4 | 110·4 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 550·00 |
| 5 | 110·7 | ·459 | 50·81 | 8·9 | 6·7 | ... | 7·3 | 241·2 | 24·00 | 574·00 |
| 6 | 110·6 | ·456 | 50·43 | 8·6 | 6·5 | ... | 7·1 | 242·6 | 23·30 | 597·30 |
| 7 | 110·4 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 621·30 |
| 8 | 110·4 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 645·30 |
| 9 | 110·2 | ·455 | 50·14 | 9·3 | 7·0 | ... | 7·6 | 242·2 | 24·00 | 669·30 |
| 10 | 110·5 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 693·30 |
| 11 | 110·4 | ·457 | 50·45 | 8·9 | 6·7 | ... | 7·3 | 241·6 | 24·00 | 717·30 |
| 12 | 110·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 741·30 |
| 13 | 111·0 | ... | ... | ... | ... | ... | ... | ... | 23·30 | 765·00 |
| 14 | 110·5 | ·458 | 50·60 | 9·2 | 6·9 | ... | 7·5 | 241·3 | 24·00 | 789·00 |
| 15 | 110·7 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 813·00 |
| 16 | 110·2 | ·458 | 50·47 | 9·7 | 7·3 | ... | 8·0 | 240·6 | 24·00 | 837·00 |
| 17 | 110·8 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 861·00 |
| 18 | 110·3 | ·457 | 50·40 | 10·1 | 7·6 | ... | 8·3 | 241·4 | 24·00 | 885·00 |
| 19 | 110·3 | ·457 | 50·40 | 8·3 | 6·2 | ... | 6·8 | 241·4 | 24·00 | 909·00 |
| 20 | 110·3 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 933·00 |
| 21 | 110·4 | ·455 | 50·23 | 9·5 | 7·1 | ... | 7·7 | 242·6 | 24·00 | 957·00 |
| 22 | 110·6 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 981·00 |
| 23 | 110·1 | ·454 | 49·98 | 8·4 | 6·3 | ... | 6·9 | 242·5 | 24·00 | 1,005·00 |
| 24 | 110·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 1,029·00 |
| *25 | 110·1 | ·455 | 50·09 | 6·9 | 5·2 | ... | 5·7 | 242·0 | 24·00 | 1,053·00 |
| 26 | ... | ... | ... | ... | ... | ... | ... | ... | 11·30 | 1,064·30 |

Resistance Cold, 455. Discoloration, 2.

## *Weston Lamp, No. 10.*

(Reduction Factor, 0·86. Resistance Cold, 421.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Mean Horizontal Candles. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 111·5 | ·529 | 58·98 | 22·15 | 19·08 | 3·09 | 20·82 | 210·8 | 0·15 | 0·15 |
| 11 | ........ | ........ | ........ | 17·0 | 14·6 | ........ | 15·9 | ........ | 3·45 | 4·00 |
| 12 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 28·00 |
| 13 | 110·5 | ·476 | 52·60 | 9·3 | 8·0 | ........ | 8·7 | 232·1 | 24·00 | 52·00 |
| 14 | 111·0 | ·477 | 52·95 | 9·9 | 8·5 | ........ | 9·3 | 232·7 | 24·00 | 76·00 |
| 15 | 111·5 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 100·00 |
| 16 | 111·9 | ·488 | 54·60 | 12·0 | 10·4 | ........ | 11·3 | 229·3 | 24·00 | 124·00 |
| 17 | 111·0 | ·482 | 53·50 | 10·6 | 9·1 | ........ | 9·9 | 230·3 | 24·00 | 148·00 |
| 18 | 110·4 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 172·00 |
| 19 | 111·7 | ·485 | 54·17 | 10·6 | 9·1 | ........ | 9·9 | 230·3 | 24·00 | 196·00 |
| 20 | 111·5 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 20·45 | 216·45 |
| 21 | 109·6 | ·480 | 52·61 | 10·5 | 9·0 | ........ | 9·8 | 228·3 | 24·00 | 240·45 |
| 22 | 109·9 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 264·45 |
| 23 | 110·4 | ·478 | 52·77 | 10·0 | 8·6 | ........ | 9·4 | 231·0 | 24·00 | 288·45 |
| 24 | 110·4 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 312·45 |
| *25 | 109·8 | ·480 | 52·70 | 10·2 | 8·8 | ........ | 9·6 | 228·7 | 24·00 | 336·45 |
| 26 | 110·5 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 21·00 | 357·45 |
| *27 | 110·1 | ·479 | 52·73 | 10·0 | 8·6 | ........ | 9·4 | 229·9 | 24·00 | 381·45 |
| *28 | 110·2 | ·480 | 52·89 | 9·0 | 7·7 | ........ | 8·4 | 229·6 | 24·00 | 405·45 |
| *29 | 110·0 | ·478 | 52·58 | 9·1 | 7·8 | ........ | 8·5 | 230·1 | 24·00 | 429·45 |
| 30 | 110·0 | ·481 | 52·91 | 13·2 | 11·4 | ........ | 12·4 | 228·7 | 24·00 | 453·45 |
| May. | | | | | | ........ | | | | |
| 1 | 109·9 | ·479 | 52·64 | 11·7 | 10·1 | ........ | 11·0 | 229·4 | 24·00 | 477·45 |
| 2 | 110·0 | ·478 | 52·58 | 11·4 | 9·8 | ........ | 10·7 | 230·1 | 24·00 | 501·45 |
| 3 | 110·5 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 525·45 |
| 4 | 110·4 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 549·45 |
| 5 | 110·3 | ·480 | 52·94 | 12·2 | 10·5 | ........ | 11·4 | 229·8 | 24·00 | 573·45 |
| 6 | 110·2 | ·477 | 52·56 | 11·4 | 9·8 | ........ | 10·7 | 231·0 | 23·30 | 597·15 |
| 7 | 110·1 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 621·15 |
| 8 | 110·4 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 645·15 |
| 9 | 110·0 | ·477 | 52·47 | 12·4 | 10·7 | ........ | 11·7 | 230·6 | 24·00 | 669·15 |
| 10 | 109·8 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 693·15 |
| 11 | 110·6 | ·480 | 53·08 | 12·4 | 10·7 | ........ | 11·7 | 230·4 | 24·00 | 717·15 |
| 12 | 111·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 741·15 |
| 13 | 111·3 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 23·30 | 764·45 |
| 14 | 110·5 | ·477 | 52·70 | 11·6 | 10·0 | ........ | 10·9 | 231·7 | 24·00 | 788·45 |
| 15 | 110·9 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 812·45 |
| 16 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 10·30 | 823·15 |

Carbon broke at side of loop 10.35 A. M., May 16, 1885. Discoloration, 2.

## *Weston Lamp, No. 12.*

(Reduction Factor, 0·87. Resistance Cold, 408.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 111·5 | ·553 | 61·66 | 25·68 | 22·26 | 2·77 | 24·45 | 201·6 | 0·30 | 0·30 |
| 11 | ........... | ........... | ........... | 16·4 | 14·3 | ........... | 15·7 | ........... | 3·45 | 4·15 |
| 12 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 28·15 |
| 13 | 109·7 | ·497 | 54·52 | 14·9 | 12·9 | 4·22 | 14·2 | 220·7 | 24·00 | 52·15 |
| 14 | 110·1 | ·493 | 54·28 | 15·5 | 13·5 | ........... | 14·8 | 223·3 | 24·00 | 76·15 |
| 15 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 5·00 | 81·15 |

Carbon broke at middle of loop 5.00 A. M., April 15, 1885. Discoloration, 2.

## *Weston Lamp, No. 13.*

(Reduction Factor, 0·80. Resistance Cold, 407.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 111·5 | ·531 | 59·20 | 20·30 | 16·27 | 3·63 | 18·13 | 210·0 | 0·30 | 0·30 |
| 11 | ........... | ........... | ........... | 15·0 | 12·0 | ........... | 13·3 | ........... | 3·45 | 4·15 |
| 12 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 28·15 |
| 13 | 110·0 | ·453 | 49·83 | 6·9 | 5·5 | 9·06 | 6·1 | 242·8 | 24·00 | 52·15 |
| 14 | 110·4 | ·453 | 50·01 | 6·8 | 5·4 | ........... | 6·0 | 243·7 | 24·00 | 76·15 |
| 15 | 111·6 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 100·15 |
| 16 | 111·7 | ·458 | 51·15 | 8·4 | 6·7 | ........... | 7·4 | 243·9 | 24·00 | 124·15 |
| 17 | 111·1 | ·455 | 50·55 | 7·5 | 6·0 | ........... | 6·7 | 244·2 | 24·00 | 148·15 |
| 18 | 110·7 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 172·15 |
| 19 | 112·0 | ·459 | 51·40 | 7·5 | 6·0 | ........... | 6·7 | 244·0 | 24·00 | 196·15 |
| 20 | 112·5 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 20·45 | 217·00 |
| 21 | 110·4 | ·450 | 49·68 | 7·5 | 6·0 | ........... | 6·7 | 245·3 | 24·00 | 241·00 |
| 22 | 110·1 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 14·30 | 255·30 |

Carbon broke at shank 2.30 P. M., April 22, 1885. Discoloration, 2.

## *Weston Lamp, No. 14.*

(Reduction Factor, 0·78. Resistance Cold, 409.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 111·4 | ·549 | 61·15 | 24·65 | 19·14 | 3·19 | 21·31 | 202·9 | 0·30 | 0·30 |
| 11 | ...... | ...... | ...... | 16·0 | 12·5 | ...... | 13·9 | ...... | 3·45 | 4·15 |
| 12 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 28·15 |
| 13 | 109·9 | ·439 | 48·25 | 4·9 | 3·8 | ...... | 4·2 | 250·3 | 24·00 | 52·15 |
| 14 | 110·5 | ·432 | 47·74 | 4·8 | 3·7 | ...... | 4·1 | 255·8 | 24·00 | 76·15 |
| 15 | 112·1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 100·15 |
| 16 | 111·7 | ·419 | 46·80 | 2·5 | 2·0 | ...... | 2·2 | 266·6 | 24·00 | 124·15 |
| 17 | 111·5 | ·412 | 45·93 | 4·0 | 3·1 | ...... | 3·4 | 270·6 | 24·00 | 148·15 |
| 18 | 110·5 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 172·15 |
| 19 | 111·8 | ·404 | 45·16 | 3·6 | 2·8 | ...... | 3·1 | 276·7 | 24·00 | 196·15 |
| 20 | 111·6 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 16·15 | 212·30 |

Carbon broke at middle of loop 7.30 P. M., April 20, 1885. Discoloration, 1.

## *Weston Lamp, No. 15.*

(Reduction Factor, 0·82. Resistance Cold, 408.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per. Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 111·4 | ·491 | 54·69 | 11·97 | 9·78 | 5·59 | 10·45 | 226·9 | 1·00 | 1·00 |
| 11 | ...... | ...... | ...... | 10·4 | 8·5 | ...... | 9·1 | ...... | 3·45 | 4·45 |
| 12 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 28·45 |
| 13 | 109·9 | ·449 | 49·35 | 6·0 | 4·9 | ...... | 5·2 | 244·8 | 24.00 | 52·45 |
| 14 | 111·0 | ·453 | 50·28 | 7·1 | 5·8 | ...... | 6·2 | 245·0 | 24·00 | 76·45 |
| 15 | 111·6 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 100·45 |
| 16 | 111·1 | ·452 | 50·21 | 8·2 | 6·7 | ...... | 7·2 | 245·8 | 24·00 | 124·45 |
| 17 | 110·8 | ·455 | 50·41 | 7·1 | 5·8 | ...... | 6·2 | 243·5 | 24·00 | 148·45 |
| 18 | 110·5 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 172·45 |
| 19 | 111·0 | ·454 | 50·39 | 7·0 | 5·7 | ...... | 6·1 | 244·5 | 20·15 | 193·00 |

Carbon broke at shank 8.15 P. M., April 19, 1885. Discoloration, 1.

## *Weston Lamp, No. 16.*

(Reduction Factor, 0·83. Resistance Cold, 399.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Mean Horizontal Candles. | Resistance Hot | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 111·4 | ·513 | 57·14 | 18·12 | 15·03 | 3·80 | 16·43 | 217·2 | 0·30 | 0·30 |
| 11 | ...... | ...... | ...... | 16·4 | 13·6 | ...... | 14·8 | ...... | 3·45 | 4·15 |
| 12 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 28·15 |
| 13 | 108·7 | ·505 | 54·89 | 13·7 | 11·4 | ...... | 12·4 | 215·3 | 24·00 | 52·15 |
| 14 | 110·4 | ·515 | 56·85 | 16·2 | 13·4 | ...... | 14·6 | 214·4 | 24·00 | 76·15 |
| 15 | 110·3 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 100·15 |
| 16 | 110·9 | ·516 | 57·22 | 20·0 | 16·6 | ...... | 18·1 | 214·9 | 24·00 | 124·15 |
| 17 | 110·6 | ·516 | 57·07 | 16·9 | 14·0 | ...... | 15·3 | 214·3 | 24·00 | 148·15 |
| 18 | 110·4 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 172·15 |
| 19 | 110·8 | ·514 | 56·95 | 16·7 | 13·9 | ...... | 15·2 | 215·6 | 24·00 | 196·15 |
| 20 | 110·6 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 20·45 | 217·00 |
| 21 | 110·4 | ·515 | 56·85 | 17·0 | 14·1 | ...... | 15·4 | 214·4 | 24·00 | 241·00 |
| 22 | 109·6 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 265·00 |
| 23 | 110·6 | ·511 | 56·51 | 14·7 | 12·2 | ...... | 13·3 | 216·4 | 24·00 | 289·00 |
| 24 | 110·5 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 313·00 |
| *25 | 110·6 | ·508 | 56·18 | 13·9 | 11·5 | ...... | 12·5 | 217·7 | 24·00 | 337·00 |
| 26 | 110·5 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 21·00 | 358·00 |
| *27 | 110·3 | ·501 | 55·26 | 13·6 | 11·3 | ...... | 12·3 | 220·2 | 24·00 | 382·00 |
| *28 | 110·7 | ·501 | 55·46 | 12·2 | 10·1 | ...... | 11·0 | 221·0 | 24·00 | 406·00 |
| *29 | 110·8 | ·500 | 55·40 | 12·1 | 10·0 | ...... | 10·9 | 221·6 | 24·00 | 430·00 |
| 30 | 111·0 | ·498 | 55·27 | 16·4 | 13·6 | ...... | 14·8 | 222·9 | 24·00 | 454·00 |
| May. | | | | | | | | | | |
| 1 | 110·8 | ·498 | 55·17 | 14·4 | 12·0 | ...... | 13·1 | 222·5 | 24·00 | 478·00 |
| 2 | 110·9 | ·497 | 55·11 | 14·3 | 11·9 | ...... | 13·0 | 223·1 | 24·00 | 502·00 |
| 3 | 110·6 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 526·00 |
| 4 | 110·4 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 550·00 |
| 5 | 110·4 | ·487 | 53·76 | 13·8 | 11·5 | ...... | 12·5 | 226·7 | 24·00 | 574·00 |
| 6 | 110·4 | ·489 | 53·98 | 12·8 | 10·6 | ...... | 11·6 | 225·8 | 23·30 | 597·30 |
| 7 | 110·2 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 621·30 |
| 8 | 110·6 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 645·30 |
| 9 | 110·1 | ·481 | 52·95 | 13·1 | 10·9 | ...... | 11·9 | 228·9 | 24·00 | 669·30 |
| 10 | 110·4 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 693·30 |
| 11 | 110·3 | ·483 | 53·27 | 12·5 | 10·4 | ...... | 11·3 | 228·4 | 24·00 | 717·30 |
| 12 | 110·2 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 741·30 |
| 13 | 111·0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 23·30 | 765·00 |
| 14 | 110·5 | ·480 | 53·04 | 12·0 | 10·0 | ...... | 10·9 | 230·2 | 24·00 | 789·00 |
| 15 | 110·7 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 813·00 |
| 16 | 110·3 | ·480 | 52·94 | 12·5 | 10·4 | ...... | 11·3 | 229·8 | 24·00 | 837·00 |
| 17 | 110·7 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 861·00 |
| 18 | 110·3 | ·475 | 52·39 | 12·7 | 10·5 | ...... | 11·4 | 232·2 | 24·00 | 885·00 |
| 19 | 110·4 | ·474 | 52·33 | 10·7 | 8·9 | ...... | 9·7 | 232·9 | 24·00 | 909·00 |
| 20 | 110·5 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 933·00 |
| 21 | 110·4 | ·472 | 52·10 | 11·6 | 9·6 | ...... | 10·5 | 233·9 | 24·00 | 957·00 |
| 22 | 110·3 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 981·00 |
| 23 | 110·1 | ·470 | 51·74 | 10·7 | 8·9 | ...... | 9·7 | 234·3 | 24·00 | 1,005·00 |
| 24 | 110·4 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 24·00 | 1,029·00 |
| *25 | 110·4 | ·468 | 51·66 | 8·5 | 7·1 | ...... | 7·7 | 235·9 | 24·00 | 1,053·00 |
| 26 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 11·30 | 1,064·30 |

Resistance Cold, 457. Discoloration, 3.

## *Weston Lamp, No. 17.*

(Reduction Factor, 0·80. Resistance Cold, 404.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 111·5 | ·521 | 58·09 | 15·35 | 12·23 | 4·75 | 14·08 | 214·0 | 1·00 | 1·00 |
| 11 | ........... | ........... | ........... | 10·6 | 8·5 | ........... | 9·8 | ........... | 3·45 | 4·45 |
| 12 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 28·45 |
| 13 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 11·45 | 40·30 |

Carbon broke at shank at 11.45 A. M., April 13, 1885. Discoloration, ½.

## *Weston Lamp, No. 19.*

(Reduction Factor, 0·73. Resistance Cold, 402.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 111·4 | ·561 | 62·49 | 27·95 | 20·30 | 3·07 | 22·93 | 198·6 | 0·30 | 0·30 |
| 11 | ........... | ........... | ........... | 20·2 | 14·7 | ........... | 16·6 | ........... | 3·45 | 4·15 |
| 12 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 28·15 |
| 13 | 109·8 | ·491 | 53·91 | 13·7 | 10·0 | 5·39 | 11·3 | 223·6 | 24·00 | 52·15 |
| 14 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 12·45 | 65·00 |

Carbon broke at side of loop at 12.45 P. M., April 14, 1885. Discoloration, 2.

## *Weston Lamp, No. 18.*

(Reduction Factor, 0·80. Resistance Cold, 405.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Mean Horizontal Candles. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 111·4 | ·540 | 60·15 | 20·97 | 16·71 | 3·60 | 17·95 | 206·3 | 0·30 | 0·30 |
| 11 | ........ | ........ | ........ | 13·6 | 10·9 | ........ | 11·7 | ........ | 3·45 | 4·15 |
| 12 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 28·15 |
| 13 | 109·6 | ·448 | 49·10 | 4·6 | 3·7 | ........ | 4·0 | 244·6 | 24·00 | 52·15 |
| 14 | 111·4 | ·451 | 50·24 | 5·0 | 4·0 | ........ | 4·3 | 247·0 | 24·00 | 76·15 |
| 15 | 111·1 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 100·15 |
| 16 | 112·3 | ·441 | 49·52 | 2·8 | 2·2 | ........ | 2·4 | 254·6 | 24·00 | 124·15 |
| 17 | 110·5 | ·431 | 47·62 | 5·0 | 4·0 | ........ | 4·3 | 256·4 | 24·00 | 148·15 |
| 18 | 111·5 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 172·15 |
| 19 | 111·7 | ·433 | 48·36 | 5·5 | 4·4 | ........ | 4·7 | 258·0 | 24·00 | 196·15 |
| 20 | 112·1 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 20·45 | 217·00 |
| 21 | 111·6 | ·432 | 48·21 | 5·9 | 4·7 | ........ | 5·0 | 258·3 | 24·00 | 241·00 |
| 22 | 110·8 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 265·00 |
| 23 | 110·9 | ·423 | 46·91 | 4·5 | 3·6 | ........ | 3·9 | 262·2 | 24·00 | 289·00 |
| 24 | 110·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 313·00 |
| *25 | 110·7 | ·426 | 47·15 | 4·5 | 3·6 | ........ | 3·9 | 259·9 | 24·00 | 337·00 |
| 26 | 110·7 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 21·00 | 358·00 |
| *27 | 110·3 | ·421 | 46·43 | 4·7 | 3·8 | ........ | 4·1 | 262·0 | 24·00 | 382·00 |
| *28 | 110·6 | ·425 | 47·00 | 4·0 | 3·2 | ........ | 3·4 | 260·2 | 24·00 | 406·00 |
| *29 | 110·5 | ·425 | 46·96 | 4·5 | 3·6 | ........ | 3·9 | 260·0 | 24·00 | 430·00 |
| 30 | 110·6 | ·424 | 46·89 | 6·3 | 5·0 | ........ | 5·4 | 260·9 | 24·00 | 454·00 |
| May. | | | | | | | | | | |
| 1 | 110·4 | ·423 | 46·69 | 5·5 | 4·4 | ........ | 4·7 | 261·0 | 24·00 | 478·00 |
| 2 | 110·5 | ·422 | 46·63 | 5·3 | 4·2 | ........ | 4·5 | 261·8 | 24·00 | 502·00 |
| 3 | 110·3 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 526·00 |
| 4 | 110·3 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 550·00 |
| 5 | 110·5 | ·423 | 46·74 | 5·6 | 4·5 | ........ | 4·8 | 261·2 | 24·00 | 574·00 |
| 6 | 110·3 | ·420 | 46·32 | 5·4 | 4·3 | ........ | 4·7 | 262·6 | 23·30 | 597·30 |
| 7 | 110·2 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 621·30 |
| 8 | 110·7 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 645·30 |
| 9 | 110·0 | ·419 | 46·08 | 5·5 | 4·4 | ........ | 4·7 | 262·5 | 24·00 | 669·30 |
| 10 | 110·4 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 693·30 |
| 11 | 110·3 | ·420 | 46·32 | 5·4 | 4·3 | ........ | 4·6 | 262·6 | 24·00 | 717·30 |
| 12 | 110·2 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 741·30 |
| 13 | 110·9 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 23·30 | 765·00 |
| 14 | 110·5 | ·421 | 46·52 | 5·4 | 4·3 | ........ | 4·6 | 262·5 | 24·00 | 789·00 |
| 15 | 110·6 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 813·00 |
| 16 | 110·2 | ·421 | 46·39 | 5·5 | 4·4 | ........ | 4·7 | 261·8 | 24·00 | 837·00 |
| 17 | 110·8 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 861·00 |
| 18 | 110·2 | ·419 | 46·17 | 5·8 | 4·6 | ........ | 4·9 | 263·0 | 24·00 | 885·00 |
| 19 | 110·2 | ·421 | 46·39 | 5·0 | 4·0 | ........ | 4·3 | 261·8 | 24·00 | 909·00 |
| 20 | 110·3 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 933·00 |
| 21 | 110·3 | ·417 | 45·99 | 5·5 | 4·4 | ........ | 4·7 | 264·5 | 24·00 | 957·00 |
| 22 | 110·3 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 981·00 |
| 23 | 109·9 | ·415 | 45·60 | 5·2 | 4·2 | ........ | 4·5 | 264·8 | 24·00 | 1,005·00 |
| 24 | 110·1 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 1,029·00 |
| *25 | 110·0 | ·418 | 45·98 | 4·0 | 3·2 | ........ | 3·4 | 263·2 | 24·00 | 1,053·00 |
| 26 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 11·30 | 1,064·30 |

Resistance Cold, 488. Discoloration, 2.

## *Weston Lamp, No. 20.*

(Reduction Factor, 0·90. Resistance Cold, 392.)

| Date. | Volts. | Ampéres. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. April. | 111·4 | ·562 | 62·60 | 21·68 | 19·44 | 3·22 | 20·88 | 198·2 | 0·30 | 0·30 |
| 11 | ... | ... | ... | 12·1 | 10·9 | ... | 11·7 | ... | 3·45 | 4·15 |
| 12 | ... | ... | ... | ... | ... | ... | ... | ... | 24·00 | 28·15 |
| 13 | 109·9 | ·488 | 53·63 | 7·7 | 6·9 | ... | 7·4 | 225·2 | 24·00 | 52·15 |
| 14 | 111·3 | ·495 | 55·10 | 8·2 | 7·4 | ... | 7·9 | 224·8 | 24·00 | 76·15 |
| 15 | 110·6 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 100·15 |
| 16 | 112·2 | ·502 | 56·32 | 11·2 | 10·0 | ... | 10·7 | 223·5 | 24·00 | 124·15 |
| 17 | 111·9 | ·499 | 55·83 | 10·3 | 9·3 | ... | 10·0 | 224·2 | 24·00 | 148·15 |
| 18 | 111·4 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 172·15 |
| 19 | 111·1 | ·491 | 54·55 | 9·5 | 8·6 | ... | 9·2 | 226·3 | 24·00 | 196·15 |
| 20 | 112·0 | ... | ... | ... | ... | ... | ... | ... | 20·45 | 217·00 |
| 21 | 111·0 | ·496 | 55·05 | 9·9 | 8·9 | ... | 9.5 | 223·8 | 24·00 | 241·00 |
| 22 | 110·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 265·00 |
| 23 | 109·9 | ·484 | 53·19 | 8·2 | 7·4 | ... | 7·9 | 227·1 | 24 00 | 289·00 |
| 24 | 109·9 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 313·00 |
| *25 | 110·0 | ·491 | 54·01 | 8·3 | 7·5 | ... | 8·0 | 224·0 | 24·00 | 337·00 |
| 26 | 109·9 | ... | ... | ... | ... | ... | ... | ... | 21·00 | 358·00 |
| *27 | 109·9 | ·490 | 53·85 | 8·8 | 7·9 | ... | 8·5 | 224·3 | 24·00 | 382·00 |
| *28 | 110·5 | ·491 | 54·25 | 7·7 | 6·9 | ... | 7·4 | 225·1 | 24·00 | 406·00 |
| *29 | 110·5 | ·493 | 54·47 | 8·1 | 7·3 | ... | 7·8 | 224·1 | 24·00 | 430·00 |
| 30 | 110·6 | ·493 | 54·52 | 11·5 | 10·4 | ... | 11·1 | 224·3 | 24·00 | 454·00 |
| May. | | | | | | | | | | |
| 1 | 110·4 | ·490 | 54·09 | 10·0 | 9·0 | ... | 9·6 | 225·3 | 24·00 | 478·00 |
| 2 | 110·6 | ·494 | 54·63 | 9·8 | 8·8 | ... | 9·4 | 223·9 | 24·00 | 502·00 |
| 3 | 110·4 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 526·00 |
| 4 | 110·3 | ... | ... | ... | ... | ... | ... | ... | 24 00 | 550·00 |
| 5 | 110·5 | ·494 | 54·58 | 10·5 | 9·5 | ... | 10·2 | 223·7 | 24·00 | 574·00 |
| 6 | 110·4 | ·489 | 53·98 | 9·7 | 8·7 | ... | 9·3 | 225·8 | 23·30 | 597·30 |
| 7 | 110·2 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 621·30 |
| 8 | 110·4 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 645·30 |
| 9 | 110·0 | ·487 | 53·57 | 10·6 | 9·5 | ... | 10·2 | 225·9 | 24·00 | 669·30 |
| 10 | 110·3 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 693·30 |
| 11 | 110·1 | ·489 | 53·83 | 10·3 | 9·3 | ... | 10·0 | 225·2 | 24·00 | 717·30 |
| 12 | 110·3 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 741·30 |
| 13 | 110·9 | ... | ... | ... | ... | ... | ... | ... | 23·30 | 765·00 |
| 14 | 110·4 | ·490 | 54·09 | 10·2 | 9·2 | ... | 9·8 | 225·3 | 24·00 | 789·00 |
| 15 | 110·6 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 813·00 |
| 16 | 110·0 | ·490 | 53·90 | 10·7 | 9·6 | ... | 10·3 | 224·5 | 24·00 | 837·00 |
| 17 | 110·4 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 861·00 |
| 18 | 110·0 | ·488 | 53·68 | 11·1 | 10·0 | ... | 10·7 | 225·4 | 24·00 | 885·00 |
| 19 | 110·5 | ·490 | 54·14 | 9·6 | 8·6 | ... | 9·2 | 225·5 | 24·00 | 909·00 |
| 20 | 110·7 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 933·00 |
| 21 | 110·8 | ·489 | 54·18 | 10·8 | 9·7 | ... | 10·4 | 226·6 | 24·00 | 957·00 |
| 22 | 110·8 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 981·00 |
| 23 | 110·4 | ·486 | 53·65 | 10·6 | 9·5 | ... | 10·2 | 227·2 | 24·00 | 1,005·00 |
| 24 | 110·1 | ... | ... | ... | ... | ... | ... | ... | 24·00 | 1,029·00 |
| *25 | 110·3 | ·484 | 53·38 | 7·9 | 7·1 | ... | 7·6 | 227·9 | 24·00 | 1,053·00 |
| 26 | ... | ... | ... | ... | ... | ... | ... | ... | 11·30 | 1,064·30 |

Resistance Cold not measured. Discoloration, 2.

# Weston Lamps, 70 Volts

## *Weston Lamp, No. 51.*

(Reduction Factor, 0·84· Resistance Cold, 152.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean. Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 70·2 | ·963 | 67·60 | 17·35 | 14·53 | 4·65 | 16·22 | 72·90 | 0·30 | 0·30 |
| 4 | 70·0 | ·951 | 66·57 | 16·8 | 14·1 | … | 15·8 | 73·61 | 9·00 | 9·30 |
| 5 | 70·2 | ·938 | 65·84 | 16·3 | 13·7 | … | 15·3 | 74·84 | 24·00 | 33·30 |
| 6 | 69·7 | ·922 | 64·26 | 14·3 | 12·0 | … | 13·4 | 75·60 | 23·30 | 57·00 |
| 7 | 70·1 | ·911 | 63·86 | 13·4 | 11·3 | … | 12·7 | 76·95 | 24·00 | 81·00 |
| 8 | 71·0 | … | … | … | … | … | … | … | 24·00 | 105·00 |
| 9 | 70·6 | ·891 | 62·90 | 12·7 | 10·7 | … | 12·0 | 79·24 | 24·00 | 129·00 |
| 10 | 70·5 | … | … | … | … | … | … | … | 24·00 | 153·00 |
| 11 | 69·9 | ·864 | 60·39 | 10·1 | 8·5 | … | 9·5 | 80·90 | 24·00 | 177·00 |
| 12 | 70·3 | … | … | … | … | … | … | … | 24·00 | 201·00 |
| 13 | 70·9 | … | … | … | … | … | … | … | 23·30 | 224·30 |
| 14 | 69·7 | ·833 | 58·06 | 8·8 | 7·4 | … | 8·3 | 83·67 | 24·00 | 248·30 |
| 15 | … | … | … | … | … | … | … | … | 11·00 | 259·30 |

Carbon broke at shank 11.00 A. M., May 15, 1885. Discoloration, 2½.

## *Weston Lamp, No. 54.*

(Reduction Factor, 0·83. Resistance Cold, 149·0.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 70·4 | ·959 | 67·51 | 17·33 | 14·46 | 4·66 | 15·73 | 73·41 | 0·45 | 0·45 |
| 4 | 70·3 | ·948 | 66·64 | 16·5 | 13·7 | … | 14·9 | 74·16 | 9·00 | 9·45 |
| 5 | 69·9 | ·944 | 65·98 | 16·4 | 13·6 | … | 14·8 | 74·05 | 24·00 | 33·45 |
| 6 | … | ·942 | … | 15·4 | 12·8 | … | 14·0 | … | 23·30 | 57·15 |
| 7 | 70·0 | ·946 | 66·22 | 16·1 | 13·4 | … | 14·6 | 74·00 | 24·00 | 81·15 |
| 8 | 70·2 | … | … | … | … | … | … | … | 24·00 | 105·15 |
| 9 | 69·9 | ·948 | 66·26 | 17·8 | 14·8 | … | 16·1 | 73·74 | 24·00 | 129·15 |
| 10 | 70·1 | … | … | … | … | … | … | … | 24·00 | 153·15 |
| 11 | 70·0 | ·952 | 66·64 | 18·6 | 15·4 | … | 16·8 | 73·53 | 24·00 | 177·15 |
| 12 | 69·8 | … | … | … | … | … | … | … | 24·00 | 201·15 |
| 13 | 69·6 | … | … | … | … | … | … | … | 23·30 | 224·45 |
| 14 | 70·1 | ·954 | 66·87 | 16·7 | 13·9 | … | 15·2 | 73·48 | 24·00 | 248·45 |
| *15 | 70·0 | ·951 | 66·57 | 18·4 | 15·3 | … | 16·7 | 73·61 | 24·00 | 272·45 |
| 16 | 70·0 | ·953 | 66·71 | 17·5 | 14·5 | … | 15·8 | 73·45 | 24·00 | 296·45 |
| 17 | 70·4 | … | … | … | … | … | … | … | 24·00 | 320·45 |
| 18 | 69·8 | ·951 | 66·38 | 17·5 | 14·5 | … | 15·6 | 73·40 | 24·00 | 344·45 |
| 19 | 69·9 | … | … | … | … | … | … | … | 24·00 | 368·45 |
| 20 | 69·9 | ·951 | 66·47 | 17·2 | 14·3 | … | 15·4 | 73·50 | 24·00 | 392·45 |
| 21 | 70·1 | … | … | … | … | … | … | … | 24·00 | 416·45 |
| 22 | 69·8 | ·948 | 66·17 | 17·0 | 14·1 | … | 14·4 | 73·63 | 24·00 | 440·45 |
| 23 | 69·8 | ·949 | 66·24 | 15·5 | 12·9 | … | 14·1 | 73·55 | 24·00 | 464·45 |
| 24 | 70·0 | … | … | … | … | … | … | … | 24·00 | 488·45 |
| *25 | 69·9 | ·952 | 66·54 | 12·7 | 10·5 | … | 11·4 | 73·43 | 24·00 | 512·45 |
| 26 | … | … | … | … | … | … | … | … | 11·30 | 524·15 |

Resistance Cold, 148. Discoloration, 2.

## *Weston Lamp, No. 55.*

(Reduction Factor, 0·82. Resistance Cold, 144.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 70·4 | 1·002 | 70·54 | 20·80 | 17·11 | 4·12 | 18·83 | 70·26 | 0·15 | 0·15 |
| 4 | 70·0 | ·988 | 69·16 | 19·9 | 16·3 | ........... | 17·9 | 70·85 | 8·45 | 9·00 |
| 5 | 70·0 | ·974 | 68·18 | 19·7 | 16·2 | ........... | 17·8 | 71·87 | 24·00 | 33·00 |
| 6 | ........... | ·975 | ........... | 17·5 | 14·4 | ........... | 15·8 | ........... | 23·30 | 56·30 |
| 7 | 69·9 | ·971 | 67·87 | 18·6 | 15·3 | ........... | 16·8 | 71·99 | 24·00 | 80·30 |
| 8 | 70·1 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 104·30 |
| 9 | 69·8 | ·972 | 67·84 | 19·5 | 16·0 | ........... | 17·6 | 71·81 | 24·00 | 128·30 |
| 10 | 70·1 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 152·30 |
| 11 | 69·9 | ·975 | 68·15 | 18·7 | 15·3 | ........... | 16·8 | 71·69 | 24·00 | 176·30 |
| 12 | 70·0 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 200·30 |
| 13 | 69·9 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 23·30 | 224·00 |
| 14 | 70·1 | ·972 | 68·13 | 18·7 | 15·3 | ........... | 16·8 | 72·12 | 24·00 | 248·00 |
| *15 | 69·9 | ·974 | 68·08 | 20·6 | 16·9 | ........... | 18·6 | 71·77 | 24·00 | 272·00 |
| 16 | 70·0 | ·977 | 68·39 | 19·5 | 16·0 | ........... | 17·6 | 71·65 | 24·00 | 296·00 |
| 17 | 70·3 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 320·00 |
| 18 | 69·9 | ·974 | 68·08 | 20·1 | 16·5 | ........... | 18·2 | 71·77 | 24·00 | 344·00 |
| 19 | 69·9 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 368·00 |
| 20 | 69·9 | ·972 | 67·94 | 19·6 | 16·1 | ........... | 17·7 | 71·91 | 24·00 | 392·00 |
| 21 | 70·3 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 416·00 |
| 22 | 69·9 | ·969 | 67·73 | 18·8 | 15·4 | ........... | 16·9 | 72·14 | 24·00 | 440·00 |
| 23 | 70·0 | ·971 | 67·97 | 18·1 | 14·8 | ........... | 16·3 | 72·09 | 24·00 | 464·00 |
| 24 | 70·0 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 488·00 |
| *25 | 70·0 | ·969 | 67·83 | 14·4 | 11·8 | ........... | 13·0 | 72·24 | 24·00 | 512·00 |
| 26 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 11·30 | 523·30 |

Resistance Cold, 147. Discoloration, 2.

## *Weston Lamp, No. 56.*

(Reduction Factor, 0·83. Resistance Cold, 148.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 70·4 | ·969 | 68·21 | 18·10 | 15·07 | 4·52 | 16·96 | 72·65 | 0·15 | 0·15 |
| 4 | 69·8 | ·953 | 66·52 | 17·4 | 14·4 | ………… | 16·3 | 73·24 | 8·45 | 9·00 |
| 5 | 69·8 | ·955 | 66·65 | 18·4 | 15·3 | ………… | 17·3 | 73·09 | 24·00 | 33·00 |
| 6 | ………… | ·955 | ………… | 17·4 | 14·4 | ………… | 16·3 | ………… | 23·30 | 56·30 |
| 7 | 69·9 | ·960 | 67·10 | 18·2 | 15·1 | ………… | 17·1 | 72·81 | 24·00 | 80·30 |
| 8 | 70·0 | ………… | ………… | ………… | ………… | ………… | ………… | ………… | 24·00 | 104·30 |
| 9 | 69·7 | ·962 | 67·05 | 19·3 | 16·0 | ………… | 18·1 | 72·45 | 24·00 | 128·30 |
| 10 | 69·9 | ………… | ………… | ………… | ………… | ………… | ………… | ………… | 24·00 | 152·30 |
| 11 | 69·8 | ·967 | 67·49 | 18·4 | 15·3 | ………… | 17·3 | 72·18 | 24·00 | 176·30 |
| 12 | 69·8 | ………… | ………… | ………… | ………… | ………… | ………… | ………… | 24·00 | 200·30 |
| 13 | 69·8 | ………… | ………… | ………… | ………… | ………… | ………… | ………… | 23·30 | 224·00 |
| 14 | 70·0 | ·966 | 67·62 | 17·8 | 14·8 | ………… | 16·7 | 72·46 | 24·00 | 248·00 |
| *15 | 69·9 | ·964 | 67·38 | 20·2 | 16·8 | ………… | 19·0 | 72·51 | 24·00 | 272·00 |
| 16 | 69·8 | ·964 | 67·28 | 19·3 | 16·0 | ………… | 18·1 | 72·41 | 24·00 | 296·00 |
| 17 | 70·1 | ………… | ………… | ………… | ………… | ………… | ………… | ………… | 24·00 | 320·00 |
| 18 | 69·7 | ·965 | 67·26 | 19·2 | 15·9 | ………… | 18·0 | 72·23 | 24·00 | 344·00 |
| 19 | 69·8 | ………… | ………… | ………… | ………… | ………… | ………… | ………… | 24·00 | 368·00 |
| 20 | 69·9 | ·965 | 67·45 | 18·7 | 15·5 | ………… | 17·5 | 72·44 | 24·00 | 392·00 |
| 21 | 70·2 | ………… | ………… | ………… | ………… | ………… | ………… | ………… | 24·00 | 416·00 |
| 22 | 69·8 | ·960 | 67·00 | 18·5 | 15·4 | ………… | 17·4 | 72·71 | 24·00 | 440·00 |
| 23 | 69·9 | ·962 | 67·24 | 16·6 | 13·8 | ………… | ………… | 72·66 | 24.00 | 464·00 |
| 24 | 70·0 | ………… | ………… | ………… | ………… | ………… | ………… | ………… | 24·00 | 488·00 |
| *25 | 70·0 | ·964 | 67·48 | 13·9 | 11·5 | ………… | 15·6 | 72·61 | 24·00 | 512·00 |
| 26 | ………… | ………… | ………… | ………… | ………… | ………… | ………… | ………… | 11·30 | 523·30 |

Resistance Cold, 147. Discoloration, 2.

## *Weston Lamp, No. 58.*

(Reduction Factor, 0·86. Resistance Cold, 153.)

| Date. | Volts. | Amperes. | Watts. | Candles. Obrseved. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 70·5 | ·952 | 67·11 | 19·80 | 16·95 | 3·96 | 18·67 | 74·05 | 0·30 | 0·30 |
| 4 | 69·9 | ·937 | 65·49 | 19·0 | 16·3 | .......... | 17·9 | 74·60 | 8·30 | 9·00 |
| 5 | 69·9 | ·942 | 65·84 | 19·8 | 17·0 | .......... | 18·7 | 74·21 | 24·00 | 33·00 |
| 6 | 69·9 | ·939 | 65·63 | 18·6 | 16·0 | .......... | 17·6 | 74·44 | 23·30 | 56·30 |
| 7 | 69·8 | ·934 | 65·19 | 18·8 | 16·2 | .......... | 17·8 | 74·73 | 24·00 | 80·30 |
| 8 | 69·9 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 104·30 |
| 9 | 69·9 | ·935 | 65·35 | 19·6 | 16·9 | .......... | 18·6 | 74·76 | 24·00 | 128·30 |
| 10 | 70·1 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 152·30 |
| 11 | 70·1 | ·935 | 65·54 | 18·4 | 15·8 | .......... | 17·4 | 74·97 | 24·00 | 176·30 |
| 12 | 70·0 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 200·30 |
| 13 | 70·3 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 23·30 | 224·00 |
| 14 | 70·4 | ·934 | 65·75 | 18·1 | 15·6 | .......... | 17·2 | 75·37 | 24·00 | 248·00 |
| *15 | 69·6 | ·924 | 64·31 | 18·9 | 16·3 | .......... | 17·9 | 75·33 | 24·00 | 272·00 |
| 16 | 69·7 | ·926 | 64·54 | 18·2 | 15·7 | .......... | 17·3 | 75·27 | 24·00 | 296·00 |
| 17 | 70·1 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 320·00 |
| 18 | 69·7 | ·924 | 64·40 | 18·2 | 15·7 | .......... | 17·3 | 75·43 | 24·00 | 344·00 |
| 19 | 69·9 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 368·00 |
| 20 | 69·9 | ·921 | 64·37 | 17·7 | 15·2 | .......... | 16·7 | 75·90 | 24·00 | 392·00 |
| 21 | 70·1 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 416·00 |
| 22 | 69·8 | ·919 | 64·14 | 17·6 | 15·1 | .......... | 16·6 | 75·95 | 24·00 | 440·00 |
| 23 | 69·9 | ·917 | 64·09 | 15·4 | 13·2 | .......... | 14·5 | 76·23 | 24·00 | 464·00 |
| 24 | 70·0 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 24·00 | 488·00 |
| *25 | 70·0 | ·915 | 64·05 | 12·9 | 11·1 | .......... | 12·2 | 76·50 | 24·00 | 512·00 |
| 26 | .......... | .......... | .......... | .......... | .......... | .......... | .......... | .......... | 11·30 | 523·30 |

Resistance Cold, 155. Discoloration, 2½.

## *Weston Lamp, No. 59.*

(Reduction Factor, 0·81. Resistance Cold, 152.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. | 70·4 | ·944 | 66·45 | 19·78 | 16·04 | 4·14 | 18·12 | 74·58 | 0·15 | 0·15 |
| May. 4 | 69·9 | ·937 | 65·49 | 19·4 | 15·7 | ........... | 17·7 | 74·60 | 8·15 | 8·30 |
| 5 | 70.0 | ·924 | 64·68 | 17·6 | 14·3 | ........... | 16·2 | 75·76 | 24·00 | 32·30 |
| 6 | 70.0 | ·924 | 64·68 | 17·5 | 14·2 | ........... | 16·0 | 75·76 | 23·30 | 56·00 |
| 7 | 69·9 | ·922 | 64·44 | 18·3 | 14·8 | ........... | 16·7 | 75·81 | 24·00 | 80·00 |
| 8 | 70·2 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 104·00 |
| 9 | 69·9 | ·922 | 64·44 | 19·1 | 15·5 | ........... | 17·5 | 75·81 | 24·00 | 128·00 |
| 10 | 70·1 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 152·00 |
| 11 | 70·1 | ·905 | 63·44 | 18·5 | 15·0 | ........... | 17·0 | 77·46 | 24·00 | 176·00 |
| 12 | 70·3 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 200·00 |
| 13 | 70·3 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 22·30 | 222·30 |

Carbon broke at side of loop near shank 11.00 P. M., May 13, 1885. Discoloration, 2½.

## *Weston Lamp, No. 61.*

(Reduction Factor, 0·84. Resistance Cold, 153.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. | 70·3 | ·969 | 68·12 | 15·48 | 13·06 | 5·21 | 14·23 | 72·55 | 0·30 | 0·30 |
| May. 4 | 70·0 | ·960 | 67·20 | 16·4 | 13·8 | ........... | 15·0 | 72·92 | 8·15 | 8·45 |
| 5 | 70·1 | ·956 | 67·01 | 16·6 | 13·9 | ........... | 15·0 | 73·33 | 24·00 | 32·45 |
| 6 | 70·0 | ·959 | 67·13 | 14·8 | 12·4 | ........... | 13·5 | 72·99 | 23·30 | 56·15 |
| 7 | 69·8 | ·956 | 66·73 | 15·3 | 12·9 | ........... | 14·0 | 73·01 | 24·00 | 80·15 |
| 8 | 69·9 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 104·15 |
| 9 | 69·5 | ·960 | 66·71 | 15·6 | 13·1 | ........... | 14·3 | 72·40 | 24·00 | 128·15 |
| 10 | 69·9 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 152·15 |
| 11 | 70·3 | ·974 | 68·47 | 16·1 | 13·5 | ........... | 14·7 | 72·18 | 24·00 | 176·15 |
| 12 | 70·0 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 200·15 |
| 13 | 70·4 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 23·30 | 223·45 |
| 14 | 70·0 | ·972 | 68·04 | 14·7 | 12·3 | ........... | 13·4 | 72·02 | 24·00 | 247·45 |
| *15 | 70·1 | ·974 | 68·27 | 18·5 | 15·5 | ........... | 16·9 | 71·97 | 24·00 | 271·45 |
| 16 | 70·0 | ·972 | 68·04 | 16·3 | 13·7 | ........... | 14·9 | 72·02 | 24·00 | 295·45 |
| 17 | 70·1 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 319·45 |
| 18 | 69·7 | ·972 | 67·74 | 16·8 | 14·1 | ........... | 15·4 | 71·71 | 24·00 | 343·45 |
| 19 | 69·9 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 367·45 |
| 20 | 69·7 | ·972 | 67·74 | 15·7 | 13·2 | ........... | 14·4 | 71·71 | 24·00 | 391·45 |
| 21 | 70·0 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 415·45 |
| 22 | 69·6 | ·969 | 67·44 | 15·5 | 13·0 | ........... | 14·2 | 71·83 | 24·00 | 439·45 |
| 23 | 69·6 | ·969 | 67·44 | 14·5 | 12·2 | ........... | 13·3 | 71·83 | 24·00 | 463·45 |
| 24 | 70·2 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 487·45 |
| *25 | 70·1 | ·980 | 68·69 | 12·3 | 10·3 | ........... | 11·2 | 71·53 | 24·00 | 511·45 |
| 26 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 11·30 | 523·15 |

Resistance Cold, 147. Discoloration, 2.

## *Weston Lamp, No. 62.*

(Reduction Factor, 0·80. Resistance Cold, 148.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 70·4 | ·971 | 68·35 | 18·02 | 14·42 | 4·74 | 16·03 | 72·50 | 0·15 | 0·15 |
| 4 | 69·7 | ·960 | 66·91 | 16·6 | 13·3 | ........... | 14·8 | 72·60 | 8·15 | 8·30 |
| 5 | 69·9 | ·938 | 65·56 | 12·0 | 9·6 | ........... | 10·7 | 74·52 | 24·00 | 32·30 |
| 6 | 69·9 | ·934 | 65·28 | 11·5 | 9·2 | ........... | 10·2 | 74·84 | 23·30 | 56·00 |
| 7 | 69·9 | ·928 | 64·86 | 11·6 | 9·3 | ........... | 10·3 | 75·32 | 24·00 | 80·00 |
| 8 | 69·9 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 104·00 |
| 9 | 69·8 | ·930 | 64·91 | 12·4 | 9·9 | ........... | 11·0 | 75·06 | 24·00 | 128·00 |
| 10 | 70·1 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 152·00 |
| 11 | 70·1 | ·934 | 65·47 | 11·9 | 9·5 | ........... | 10·5 | 75·05 | 24·00 | 176·00 |
| 12 | 70·1 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 200·00 |
| 13 | 70·0 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 23·30 | 223·30 |
| 14 | 70·1 | ·936 | 65·61 | 11·6 | 9·3 | ........... | 10·3 | 74·89 | 24·00 | 247·30 |
| *15 | 70·1 | ·934 | 65·47 | 13·8 | 11·0 | ........... | 12·2 | 75·05 | 24·00 | 271·30 |
| 16 | 69·9 | ·933 | 65·21 | 12·6 | 10·1 | ........... | 11·2 | 74·92 | 24·00 | 295·30 |
| 17 | 70·2 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 319·30 |
| 18 | 69·7 | ·932 | 64·96 | 13·1 | 10·5 | ........... | 11·7 | 74·78 | 24·00 | 343·30 |
| 19 | 69·9 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 367·30 |
| 20 | 69·9 | ·933 | 65·21 | 13·2 | 10·6 | ........... | 11·8 | 74·92 | 24·00 | 391·30 |
| 21 | 70·1 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 415·30 |
| 22 | 69·9 | ·931 | 65·07 | 12·6 | 10·1 | ........... | 11·2 | 75·08 | 24·00 | 439·30 |
| 23 | 69·7 | ·931 | 64·89 | 12·0 | 9·6 | ........... | 10·2 | 74·87 | 24·00 | 463·30 |
| 24 | 69·9 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 487·30 |
| *25 | 69·8 | ·932 | 65·05 | 11·3 | 9·0 | ........... | 10·0 | 74·89 | 24·00 | 511·30 |
| 26 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 11·30 | 523·00 |

Lamp adjusted May 5, 1885. Resistance Cold, 152. Discoloration, 2.

## *Weston Lamp, No. 63.*

(Reduction Factor, 0·81 Resistance Cold, 147.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 70·4 | ·984 | 69·27 | 18·35 | 14·85 | 4·66 | 16·93 | 71·54 | 0·15 | 0·15 |
| 4 | 69·7 | ·965 | 67·26 | 16·7 | 13·5 | ........ | 15·4 | 72·23 | 8·00 | 8·15 |
| 5 | 69·9 | ·966 | 67·52 | 16·4 | 13·3 | ........ | 15·2 | 72·36 | 24·00 | 32·15 |
| 6 | 69·7 | ·960 | 66·91 | 16·2 | 13·1 | ........ | 14·9 | 72·60 | 23·30 | 55·45 |
| 7 | 70·0 | ·966 | 67·62 | 16·8 | 13·6 | ........ | 15·5 | 72·46 | 24·00 | 79·45 |
| 8 | 70·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 103·45 |
| 9 | 69·8 | ·974 | 67·98 | 17·4 | 14·1 | ........ | 16·1 | 71·66 | 24·00 | 127·45 |
| 10 | 70·1 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 151·45 |
| 11 | 69·9 | ·981 | 68·57 | 17·3 | 14·0 | ........ | 16·0 | 71·25 | 24·00 | 175·45 |
| 12 | 69·8 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 199·45 |
| 13 | 70·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 23·30 | 223·15 |
| 14 | 69·9 | ·981 | 68·57 | 16·7 | 13·5 | ........ | 15·4 | 71·25 | 24·00 | 247·15 |
| *15 | 70·0 | ·982 | 68·74 | 19·7 | 16·0 | ........ | 18·2 | 71·28 | 24·00 | 271·15 |
| 16 | 69·7 | ·982 | 68·44 | 17·6 | 14·3 | ........ | 16·3 | 70·98 | 24·00 | 295·15 |
| 17 | 70·0 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 319·15 |
| 18 | 69·8 | ·984 | 68·68 | 19·2 | 15·6 | ........ | 17·8 | 70·94 | 24·00 | 343·15 |
| 19 | 69·9 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 367·15 |
| 20 | 69·9 | ·985 | 68·85 | 18·6 | 15·1 | ........ | 17·2 | 70·97 | 24·00 | 391·15 |
| 21 | 70·1 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 415·15 |
| 22 | 69·7 | ·982 | 68·44 | 18·4 | 14·9 | ........ | 17·0 | 70·98 | 24·00 | 439·15 |
| 23 | 69·8 | ·984 | 68·68 | 17·0 | 13·8 | ........ | 15·7 | 70·94 | 24·00 | 463·15 |
| 24 | 69·9 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 24·00 | 487·15 |
| *25 | 69·7 | ·985 | 68·65 | 13·6 | 11·0 | ........ | 12·5 | 70·76 | 24·00 | 511·15 |
| 26 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 11·30 | 522·45 |

Resistance Cold, 145. Discoloration, 1½.

## *Weston Lamp, No. 64.*

(Reduction Factor, 0·85. Resistance Cold, 149.)

| Date. | Volts. | Amperes. | Watts. | Candles. Observed. | Candles. Spherical. | Watts per Spher. Cand. | Candles. Mean Horizontal. | Resistance Hot. | Hours. | Total Hours. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1885. May. | 70·4 | ·962 | 67·72 | 18·00 | 15·32 | 4·42 | 16·76 | 73·18 | 0·15 | 0·15 |
| 4 | 69·9 | ·952 | 66·54 | 17·6 | 15·0 | ........... | 16·4 | 73·43 | 8·00 | 8·15 |
| 5 | 69·8 | ·955 | 66·65 | 18·0 | 15·3 | ........... | 16·7 | 73·09 | 24·00 | 32·15 |
| 6 | 69·7 | ·954 | 66·49 | 17·0 | 14·5 | ........... | 15·8 | 73·06 | 23·30 | 55·45 |
| 7 | 70·1 | ·957 | 67·08 | 18·3 | 15·6 | ........... | 17·0 | 73·25 | 24·00 | 79·45 |
| 8 | 70·2 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 103·45 |
| 9 | 69·9 | ·960 | 67·10 | 18·7 | 15·9 | ........... | 17·3 | 72·81 | 24·00 | 127·45 |
| 10 | 70·3 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 151·45 |
| 11 | 70·1 | ·965 | 67·64 | 18·5 | 15·7 | ........... | 17·1 | 72·64 | 24·00 | 175·45 |
| 12 | 70·3 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 199·45 |
| 13 | 70·1 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 23·30 | 223·15 |
| 14 | 70·3 | ·962 | 67·63 | 18·4 | 15·6 | ........... | 17·0 | 73·08 | 24·00 | 247·15 |
| *15 | 69·9 | ·956 | 66·82 | 19·1 | 16·2 | ........... | 17·7 | 73·12 | 24·00 | 271·15 |
| 16 | 69·6 | ·954 | 66·39 | 18·1 | 15·4 | ........... | 16·8 | 72·96 | 24·00 | 295·15 |
| 17 | 70·0 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 319·15 |
| 18 | 69·8 | ·954 | 66·59 | 19·0 | 16·2 | ........... | 17·7 | 73·17 | 24·00 | 343·15 |
| 19 | 69·9 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 367·15 |
| 20 | 69·9 | ·954 | 66·68 | 18·3 | 15·6 | ........... | 17·0 | 73·27 | 24·00 | 391·15 |
| 21 | 70·2 | ........... | ........... | ........... | ........... | ........... | ........... | ........... | 24·00 | 415·15 |
| 22 | 69·8 | ·947 | 66·10 | 17·8 | 15·1 | ........... | 16·5 | 73·71 | 24·00 | 439·15 |
| 23 | 69·9 | ·946 | 66·12 | 16·4 | 13·9 | ........... | 15·1 | 73·89 | 22·45 | 462·00 |

Carbon broke at side of loop near shank 10.45 P. M., May 23, 1885. Discoloration, 2.

The Committee return their thanks for the loan of apparatus and for other favors extended to them, which greatly facilitated their work. They wish in particular to express their grateful appreciation of the courtesy and assistance uniformly shown them by Mr. W. P. Tatham, the President of the FRANKLIN INSTITUTE, under whose direction the tests were conducted. Everything in his power has been cheerfully and promptly done to facilitate their work.

J. B. MURDOCK,
L. DUNCAN,
G. M. WARD,
WM. D. MARKS.

1884—INTERNATIONAL ELECTRICAL EXHIBITION—1884

OF THE

FRANKLIN INSTITUTE, OF THE STATE OF PENNSYLVANIA,

FOR THE

PROMOTION OF THE MECHANIC ARTS.

# REPORTS OF THE EXAMINERS

OF

# SECTION XII.

*(SECTION I, CLASS VI. OF THE CATALOGUE.)*

# GAS ENGINES.

[ISSUED BY AUTHORITY OF THE BOARD OF MANAGERS AND PUBLISHED AS A SUPPLEMENT TO THE JOURNAL OF THE FRANKLIN INSTITUTE, OCTOBER, 1885.]

PHILADELPHIA:
THE FRANKLIN INSTITUTE.
1885.

## EDITING COMMITTEE.

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# 1884—INTERNATIONAL ELECTRICAL EXHIBITION—1884

FRANKLIN INSTITUTE, Philadelphia, Pa.

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## REPORT OF EXAMINERS.

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### SECTION XII.—GAS ENGINES AND OTHER PRIME MOTORS.

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*To the Board of Managers of the* FRANKLIN INSTITUTE:

GENTLEMEN:—I have the honor to transmit herewith the report of the Examiners of Section XII. on "Gas Engines and other Prime Motors."

Respectfully,

M. B. SNYDER,
*Chairman Board of Examiners.*

PHILADELPHIA, June, 1885.

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Professor M. B. SNYDER, *Chairman Board of Examiners, International Electrical Exhibition:*

SIR:—The Examiners in Section XII. (on "Gas Engines and other Prime Motors,") respectfully present the following report.

J. BURKITT WEBB,
*Chairman of Section XII.*

ITHACA, N. Y., June, 1885.

## GAS ENGINES AND OTHER PRIME MOTORS.

Upon the organization of Section XII., it was found that their work would probably be limited to the examination of gas engines; it was therefore decided to adopt a code for these only, and to prepare for tests of a scientific character, which might solve doubtful points in the operation of these engines, and a committee was appointed to draft such a code.

At the next meeting of the Section, the following code was reported by the committee and was adopted by the Section, and a further committee was charged with the duty of making definite arrangements with the exhibitors of gas engines, whereby they should submit certain engines to be tested by the Section in accordance with the code and any necessary additional arrangements.

### CODE OF TESTS OF GAS ENGINES.

[Approved, September 8, 1884, by Section XII. of the Board of Examiners of the International Electrical Exhibition of the FRANKLIN INSTITUTE, Philadelphia, Pa.]

The aim of the experiments will be two-fold:

I. A PRACTICAL TEST to determine the efficiency of the engines exhibited under conditions regarded as the most favorable by their makers, with a view solely to the acquirement of practical information regarding the economy and reliability of the several engines.

Such determination will consist of:

(*a*.) A ten-hour test under maximum load.

(*b*.) A ten-hour test under minimum load.

(*c*.) A ten-hour test under average load, the engine being stopped at the end of each hour and the time lost in re-starting noted.

The data collected will consist of:

(1.) Indicator cards.
(2.) Prony brake readings.
(3.) Velocity and regularity of rotation.
(4.) Total number of revolutions.
(5.) Total number of explosions.
(6.) Temperatures of entering gas and air.
(7.) Temperature of exhaust gas.
(8.) Temperature of entering water.
(9.) Temperature of escaping water.
(10.) Pressures of entering gas and air.
(11.) Analysis of entering gas.
(12.) Analysis of escaping gases.

II. A Scientific Test to determine certain details of the action of the gas inside the cylinder, valuable and desirable in view of the imperfect state of our knowlage of gas engines from a theoretical standpoint.

For this purpose some one engine will be selected and the attempt made to obtain the following data, in addition to those secured in the practical test.

(1.) Temperature of gases after explosion; by means of the electrical resistance of fine platinum wire placed in the cylinder.

(2.) Effect of varying amounts of compression.

(3.) Effect of varying mixtures.

(4.) Effect of compressing the gas and using it through a reduction-of-pressure regulator.

(5.) Effect of heating the entering gas.

(6.) Inflammability of the charge by an electric spark at different points of the cylinder.

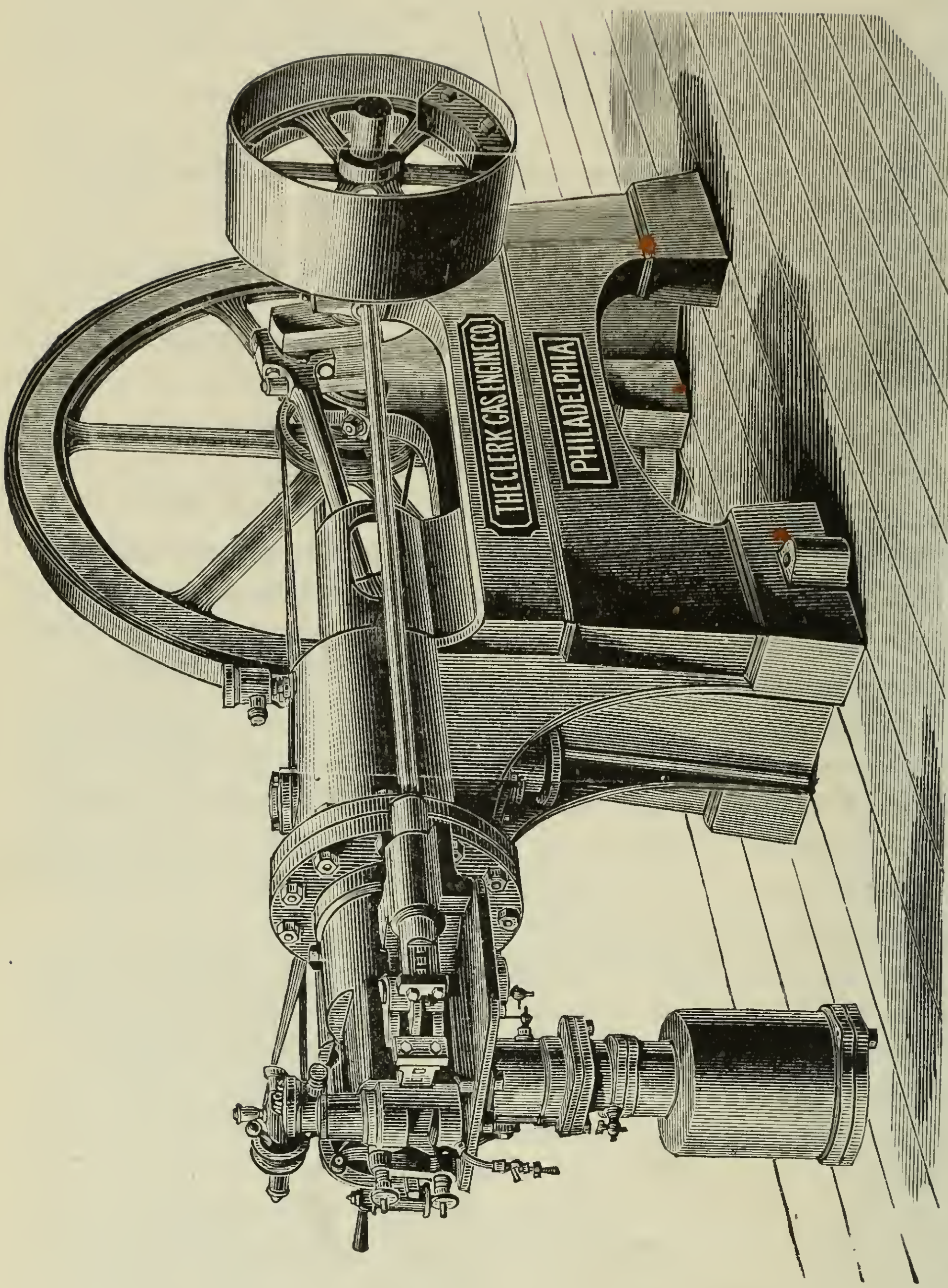
(7.) Effects of variations of speed and changes of valve settings, etc.

(8.) Dissociation experiments.

After conference with the exhibitors, the committee reported that they were unwilling to submit their gas engines to the tests proposed by the committee; no such tests were therefore made, and the report is confined to simple notices of the engines exhibited.

The Clerk Gas Engine Company, of Philadelphia, exhibit two of their engines of, respectively, eight and ten horse-power, which drive Ball unipolar dynamos, six arc lights being maintained by the smaller engine and eighty incandescent lights by the larger. This engine is constructed with two cylinders—a working cylinder, in which a mixture of gas and air is exploded at each revolution, and a "displacer" cylinder, by which the remnants of the waste gases are blown out of the working cylinder and a fresh charge of the explosive mixture furnished.

The pressure in the "displacer" cylinder is never over five pounds, the volume is, however, greater than that of the working cylinder; its piston is driven by a crank a quarter revolution in advance of the working crank. During the first half of its stroke, it sucks in a combustible mixture of gas and air, while during the remainder of the stroke only air is admitted; the first half of the return stroke, therefore, must force this half cylinder full of air into and through the working cylinder, and the combustible mixture will be forced into it during the last half of the stroke. Owing to the relation of the cranks this first half of the return stroke corresponds to the last eight of the outward and the first eight of the return stroke of the working cylinder; the air, therefore, washes

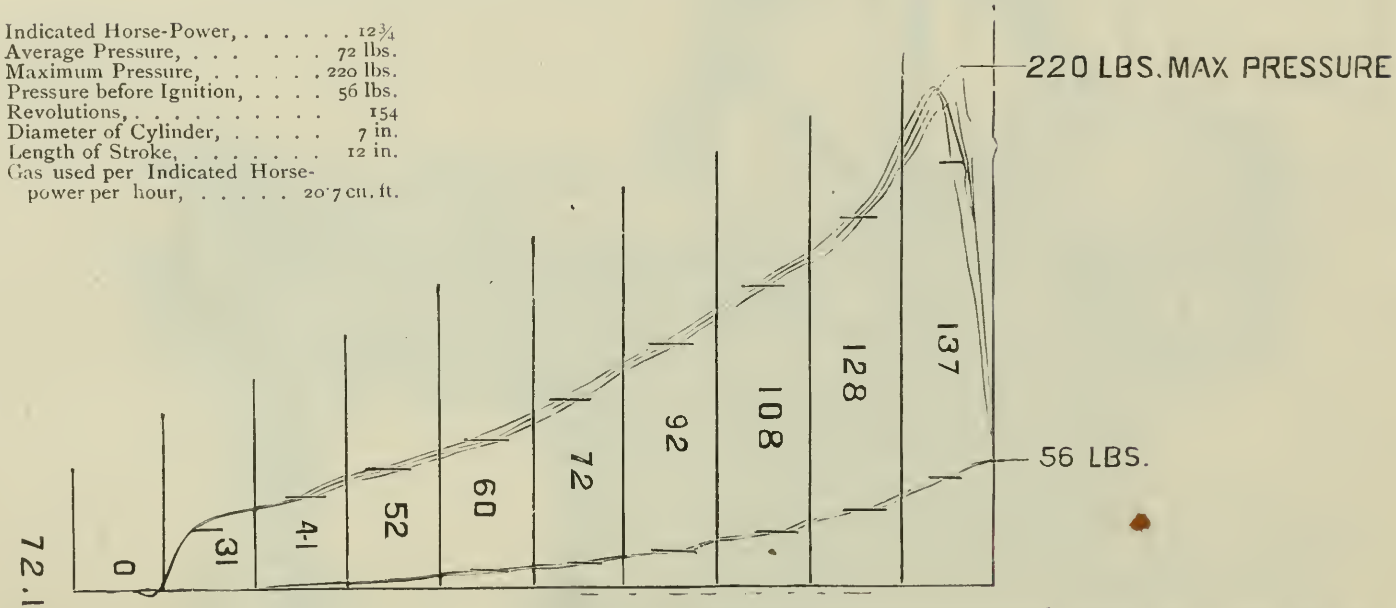



CLERK GAS ENGINE.

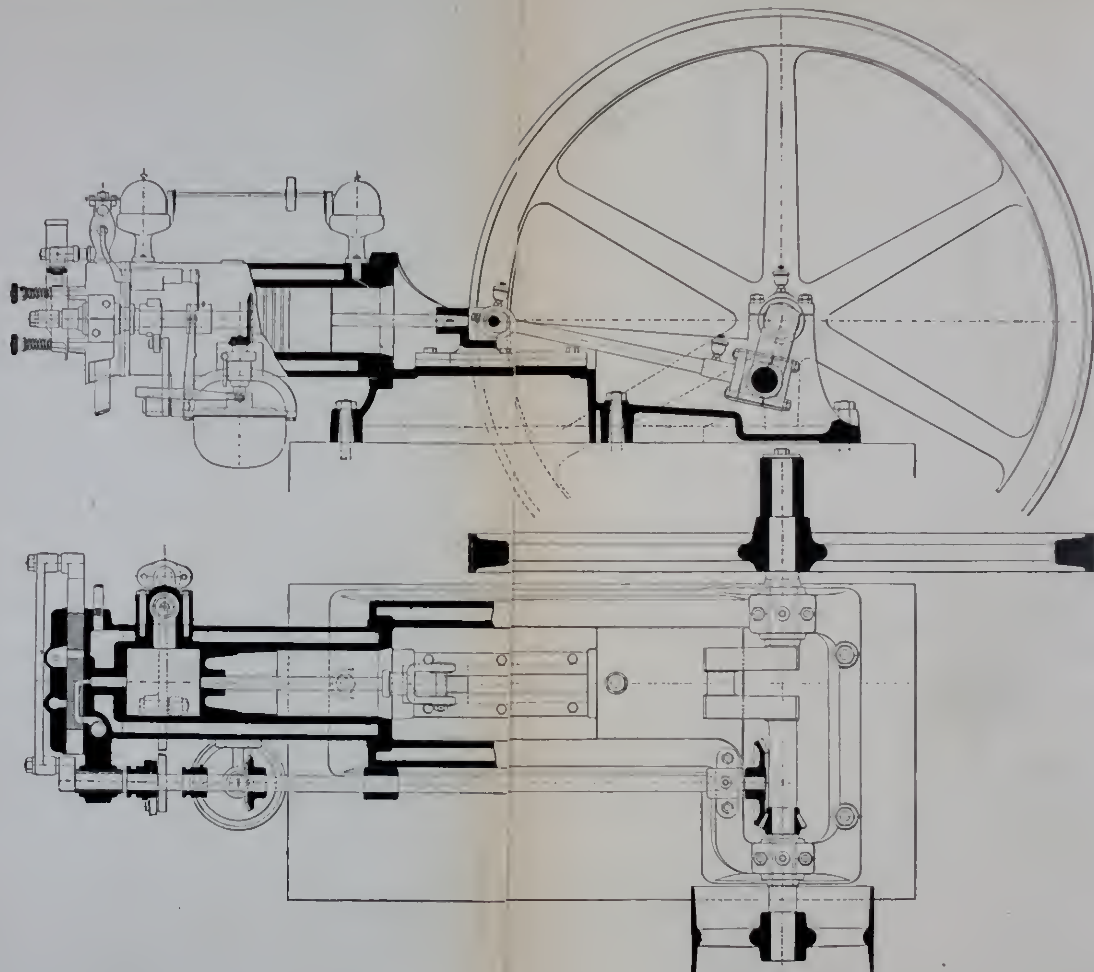
out and cools the latter while the piston is at the outward end of it. The exhaust of the working cylinder is by means of annular ports uncovered by the piston at the outward end of its stroke, and in order that the air may escape and the combustible mixture be fairly in the cylinder before these ports are closed, the volume of the "displacer" cylinder is made larger than that of the working cylinder plus its "clearance." The return stroke of the working piston compresses the mixture to say fifty pounds pressure per square inch, and it is then exploded, the pressure rising to from 200 pounds to 250 pounds. The charges are fired by means of a Bunsen burner and "ignition slide." These engines have also an attachment, by means of which compressed gas is used for starting them. This consists principally of a reservoir, into which the "displacer" cylinder can be made to compress the combustible mixture to, say, seventy pounds pressure. This is effected by a valve, which prevents the mixture from entering the working cylinder; the compression is, therefore, accomplished by the stored energy of the fly wheel and must be done a little at a time so as not to stop the engine. Following is a cut and indicator diagram of these engines, with dimensions and weights of various sizes:

DIAGRAM (furnished by the Company,) OF A 10 HORSE-POWER CLERK GAS ENGINE.

Indicated Horse-Power, . . . . . . 12¾
Average Pressure, . . . . . . . 72 lbs.
Maximum Pressure, . . . . . . 220 lbs.
Pressure before Ignition, . . . . 56 lbs.
Revolutions, . . . . . . . . . . 154
Diameter of Cylinder, . . . . . 7 in.
Length of Stroke, . . . . . . . 12 in.
Gas used per Indicated Horse-power per hour, . . . . . 20·7 cu. ft.

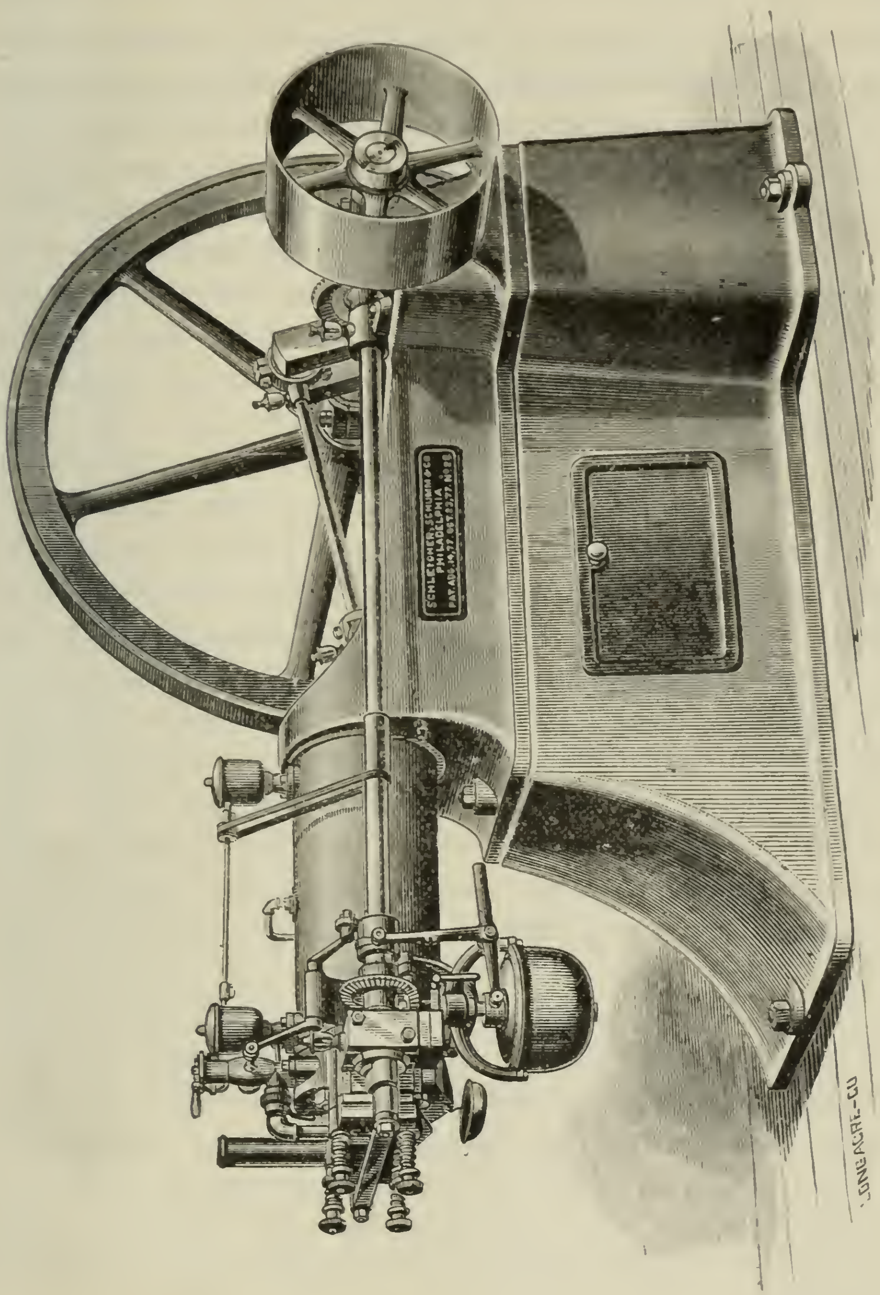



| No. of Engine. | Indicated Horse-Power. | Motor Cylinder. Diameter. | Motor Cylinder. Stroke. | Driving Pulley. Diameter. | Driving Pulley. Face. | Revolutions. | Floor Space. | Height. | Weight of Engine Complete. |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 4 to 5 | 5 in. | 8 in. | 16 in. | 6½ in. | 210 | 6 ft x 3 ft. | 2 ft. 8 in. | 2,100 lbs. |
| 2 | 8 " 9 | 6 in. | 10 in. | 18 in. | 8 in. | 180 | 8 ft x 3 ft. 5 in. | 4 ft. 9 in. | 2,700 lbs. |
| 3 | 10 " 14 | 7 in. | 12 in. | 24 in. | 10 in. | 150 | 9 ft. x 3 ft. 6 in. | 5 ft. 6 in. | 3,800 lbs. |
| 4 | 15 " 17 | 8 in. | 16 in. | 28 in. | 12 in. | 140 | 12 ft. x 3 ft. 9 in. | 6 ft. 4 in. | 5,800 lbs. |
| 5 | 25 " 27 | 9 in. | 20 in. | 32 in. | 14½ in. | 130 | 13 ft x 5 ft. | 6 ft. 4 in. | 7,800 lbs. |



SECTIONAL VIEW, (furnished by the Company) OF THE "OTTO" GAS ENGINE.

Schleicher, Schumm & Co., of Philadelphia, exhibit three of their standard "Otto" Silent Gas Engines, respectively of four, seven and fifteen horse-power, the two former driving, the first a 25-light Edison dynamo, and the second a 40-light Bernstein.




"OTTO" GAS ENGINE.

These engines have but one cylinder, in which the combustible mixture is compressed and exploded during alternate revolutions. It is claimed that this engine possesses the least number of work-

ing parts, and the greatest simplicity of mechanism ever yet attained in a gas engine, or even in many steam engines.

Messrs. Queen & Co., of Philadelphia, exhibit a small steam engine, using petroleum as a fuel and suited for use in the lecture room.

The boiler of this engine consists of a cast-iron water-back, from which project about fifty horizontal cast-iron tubes, 9 inches long by 1¼ inches diameter, the whole surrounded by a double sheet-iron jacket open underneath and terminating above in a pipe for connection with a chimney. Among these tubes is blown the flame from a petroleum atomizer, operated by live steam from the boiler and controlled by a pressure diaphragm, which shuts off the supply of steam when the boiler pressure rises above the right amount. This arrangement, entirely automatic, maintains the steam at a fixed pressure whether the engine be running or not. The supply of water is also regulated automatically by a float. Besides the arrangements described, there are also the usual steam gauge, safety valve and water glass. The engine is enclosed in a cast-iron case into which it exhausts, it is supplied with a self-oiler and the case has a pan bottom, in which the oil and condensed water collect, and from which they are splashed by the crank, etc., over the whole engine, thus keeping it well oiled. The engine is an inverted one, having two single acting cylinders end to end above the crank, with steam chest and simple cock-valve between them. The pistons have no packing and are united by a piston rod, also without packing, running through the steam chest, the connecting rod being hinged to the lower piston. The simple cock valve is operated by a movable eccentric, whose position is controlled by centrifugal force acting in opposition to a spring, and the supply of steam is thus controlled; the engine has therefore an automatic cut-off. The exhaust is by means of annular ports in the walls of the cylinders, which are uncovered by the pistons at the ends of the stroke.

At the request of Messrs. Queen & Co., and in presence of their representative, a short test was undertaken October 18, 1884, to ascertain the working qualities of the engine, and with the following results:

To start the engine it was run backwards a few times by hand, and air was thus compressed into the boiler, sufficient to run the atomizer until there was a pressure of steam sufficient to run it;

in a few minutes the pressure stood at 105 pounds. The coal oil and water were then weighed and the temperature taken, the brake adjusted, and the test commenced. The test was continued for over an hour, the engine running at about 500 revolutions per minute, with the brake adjusted to absorb the maximum amount of work, and it was found difficult to maintain the steam at more than seventy-five pounds pressure with the full load on. The general result of the test was that the engine would develop four-tenths horse-power with a consumption of five pounds fourteen ounces of oil, and twenty-six pounds of water at 70° Fahrenheit, per hour.

Respectfully submitted,

J. BURKITT WEBB, *Chairman*,
S. LLOYD WIEGAND,
W. BARNET LeVAN.
LUTHER L. CHENEY.

FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA

FOR THE

PROMOTION OF THE MECHANIC ARTS.

# Competitive Tests

OF

# Dynamo-Electric Machines.

Report of a Special Committee, appointed by the President of the Franklin Institute in conformity with a Resolution of the Board of Managers, passed November 12, 1884.

[ISSUED BY AUTHORITY OF THE BOARD OF MANAGERS AND PUBLISHED AS A SUPPLEMENT TO THE JOURNAL OF THE FRANKLIN INSTITUTE, NOVEMBER, 1885.]

PHILADELPHIA:

THE FRANKLIN INSTITUTE.

1885.

## EDITING COMMITTEE.

## FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA. FOR THE PROMOTION OF THE MECHANIC ARTS.

*To the Board of Managers of the* FRANKLIN INSTITUTE:

GENTLEMEN:—I herewith transmit the report of the Committee of Judges, consisting of Louis Duncan, Ph.D., Ensign, U. S. Navy, Chairman; William D. Marks, Whitney Professor of Dynamic Engineering, University of Pennsylvania; George L. Anderson, Lieut. U. S. Army, Instructor of Mathematics, U. S. Military Academy, West Point; J. B. Murdock, Lieut. U. S. Navy; A. B. Wyckoff, Lieut. U. S. Navy, Hydrographic Office, Philadelphia, appointed under authority of the resolution of the Board, adopted November 12, 1884, to Conduct Competitive Tests of Dynamo-Electric Machines, entered for competition by the Edison Electric Light Company, and the United States Electric Light Company, who duly accepted them as judges.

It was found impossible to constitute the committee from the list of names in the adopted code, most of those gentlemen declining to serve, or accepting under unavailable conditions.

Commander Jewell, U. S. Navy, acted as Chairman at the beginning, and rendered valuable assistance and advice in the preliminary preparations. Owing to unavoidable delays, however, the tests were not begun before his paramount duties at the U. S. Torpedo Station compelled him to withdraw.

The conditions of the code were severe upon the judges, requiring protracted runs of the machines, and immediate calculations of results. The labors of the committee were therefore incessant, and were performed with such zeal, intelligence, fidelity, and success as to satisfy me that no praise of mine could exceed that to which a careful examination of the report of their work will entitle them.

The thanks of the INSTITUTE are due not only to the judges, but also to the heads of the Departments and Bureaus of the Navy and Army, whose consent was necessary to enable the officers to take part in the work.

The INSTITUTE is under especial obligations to the Johns Hopkins University for the use of their laboratory and for assistance in comparing thermometers and resistances.

The thanks of the INSTITUTE are also due to various parties for loans of apparatus, as follows:

Baldwin Locomotive Works, for use of boiler; Buckeye Engine Company, Salem, O., for steam engine; Professors Genth and Sadtler and the department of Dynamics of the University of Pennsylvania, for platinum crucibles, indicators, resistance coils and galvanometer; U. S. Coast and Geodetic Survey, for magnetometer; Stevens Institute of Technology for tangent galvanometer; Mr. Wm. Harpur, for chronometer; Mr. Henry Trœmner, for delicate balances; Messrs. Fairbanks & Co., for beam, platform scales and standard weights; Electrical Supply Company, of New York, for voltameter; Commander Jewell, U. S. Navy, and the members of the committee, for the use of their instruments.

Very respectfully,

W. P. TATHAM, *President.*

PHILADELPHIA, September 26, 1885.

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## RESOLUTION.

[RESOLUTIONS OF THE BOARD OF MANAGERS, NOV. 22, 1884.]

WHEREAS, Through delay and lack of time on the part of many of the Examiners, several of the largest exhibits at the Electrical Exhibition have had either incomplete examination or have had none at all; therefore, be it

*Resolved*, That the President be directed to take such steps, appoint such committees, and incur such expense, not exceeding three thousand dollars, as shall be necessary to complete in a satisfactory manner the examination of exhibits.

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MR. W. P. TATHAM, *President of the* FRANKLIN INSTITUTE.

SIR:—I have the honor to herewith transmit the report of the Committee appointed to conduct the Competitive Tests of the Dynamo Electric Machines of the U. S. Electric Light and Edison Companies.

I am, very respectfully yours,

LOUIS DUNCAN, *Chairman.*

## COMPETITIVE TESTS OF DYNAMO-MACHINES.

On first organizing the committee, Commander Jewell, U. S. N. was elected Chairman, but after directing some of the preliminaries, he was compelled to resign in order to resume his duties at the U. S. Torpedo Station, at Newport.

The tests were conducted under the following code, agreed to by the contestants :

*Proposed Code for Test of Dynamo Electric Machines, to be used by the* FRANKLIN INSTITUTE *of the State of Pennsylvania.*

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### SECTION 1.

#### GENERAL CLAUSES AND CONDITIONS.

(1.) The parties hereto subscribing do agree to accept the services of the examiners herein named, and to abide by the verdict of the Judges and the methods of testing named without appeal from the decision reached.

#### LIST OF JUDGES.

(*From which five shall be chosen to act.*)

(2.) Prof. WM. A. ANTHONY, Cornell University, Ithaca, N. Y.
Prof. WM. D. MARKS, University of Pennsylvania, Philadelphia, Pa.
Prof. J. E. DENTON, Stevens Institute, Hoboken, N. J.
Prof. W. E. GEYER, Stevens Institute, Hoboken, N. J.
Lieut. J. B. MURDOCK, U. S. N., Philadelphia, Pa.
Ensign LOUIS DUNCAN, U. S. N., Johns Hopkins University.
Lieut. JOHN MILLISS, Light-House Board, New York.
OSCAR BUSSMANN, Assistant.

(3.) The FRANKLIN INSTITUTE will procure instruments, pay expenses of observers. The companies will pay for handling machines, running lines, placing and erecting lamps, and care for machines during test.

### SECTION II.

#### CONSTRUCTION OF THE MACHINE.

(4.) The following data will also be given :
Diameter of armature ;
Weight of machine ;
Number of commutator bars ;
Turns and length of wire in armature coils ;
Whether brushes must be adjusted, or are automatic for different currents ;
Diameter and length of bearings ;
Number of turns per minute ;
Number of volts for best work ;
Number of ampères for best work.

## SECTION III.

### PRELIMINARY TESTS.

(5.) The resistance of the field magnet coils and of the armature coils will be measured as follows: A strong current from a secondary battery shall be passed through these coils and ampère-meter and sensitive voltameter used to determine current and fall of potential. The resistance will be determined from these measurements. As an additional precaution, a strip of german silver of known resistance shall have its fall of potential measured with the same current and instruments. These measurements shall be made before and after the tests, with the machine hot and cold.

### INSULATION RESISTANCE.

(6.) Tests will be made of the insulation of the terminals of the machine from its metal bed-plate.

Tests will be made of the insulation resistance between the commutator and the axle.

(7.) It is understood between the parties that if any mechanical defect is observed, another machine may be substituted if the committee agree that such defect exists.

The competitors shall have reasonable opportunity to obtain information of the progress of the tests, and to know the figures of each test for the object of ascertaining errors in time for correction.

The observations made will be publicly posted before the machine is removed from the dynamometer.

### CALIBRATION OF INSTRUMENTS.

(8.) The constants of all instruments used shall be determined by at least two independent methods. The companies shall have opportunity to inspect and observe the methods used and shall be furnished with the constants of the instruments immediately after they have been determined. All objections to the methods used will be received and acted upon as provided under Section IV., Article 17.

## SECTION IV.

### QUANTITATIVE TESTS.

(9.) The dynamo to be tested will be run under full load for ten hours continuously, to see that all is in good working order before the tests begin.

(10.) For the actual test the machine shall be run and the temperatures of the pole pieces and armatures observed until a uniform temperature is reached.

(11.) When a uniform temperature for each load is reached, the measurements of power shall begin.

(12.) The machine will be tested on both live and dead resistances.

(13.) The machine will be tested on one-quarter, one-half, three-fourths, and full load. In the latter case, to be run at least five hours after a uniform temperature is reached.

(14.) Full measurements of friction and of energy expended in field will be made in each case.

DYNAMOMETRIC MEASUREMENTS.

(15.) The shaft of the dynamo will be directly attached to the end of the shaft of Tatham's dynamometer, by means of a universal joint coupling, and the horse-power used read from the dynamometer, unless the committee, for reason, shall decide otherwise.

OBSERVATIONS.

(16.) The observations on the dynamometer, current galvanometer, and potential galvanometer, and all other instruments, will be taken at synchronous intervals.

The temperature of the room will be made as even as possible, and the temperature noted and necessary corrections made.

The adjustment and oiling of machines shall be in the hands of the authorized expert for the company.

(17.) In case any objection be made, or difference of opinion should arise between the committee and the contestants, the unanimous vote of the committee shall be final.

If, however, there be not a unanimous vote, the minority of the committee shall appoint one referee and the majority another; these two shall appoint a third referee.

The decision of the majority of these referees shall be final.

In all determinations of efficiency of machines, measurement of potential shall be made (simultaneously with measurements of the current strength) at the binding posts of the machine, and at such other points of the circuit as will determine the total fall of potential, due to the resistance of the leads, connections and switches included in circuit with the instruments used for determining current strength. From these measurements, the loss shall be calculated and credited to the machine under trial.

[Signed] FRANCIS R. UPTON.

*United States Electric Lighting Company,*
*per* EDWARD WESTON, *Electrician.*

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*Plate I* gives the general arrangement of the apparatus. The test room, in which most of the instruments for electrical measurement were placed, was in about the middle of the Exhibition Building of the FRANKLIN INSTITUTE. The dynamos, with the boiler and engine used in running them, were in a shed at one corner of the building; and the resistances for their external circuit, —lamps and german silver strips—in a room inside the building and very near the shed.

The storage battery, tangent galvanometer for current calibrations, and galvanometer for measuring field currents, were in different parts of the building, far enough from the test room not to affect the instruments in it.

The leads from the dynamos and storage battery, and to the tangent galvanometer were of heavy, insulated copper cable. They were taken to the corner of the test house farthest from the instruments, and where they approached it the two parts of a circuit were twisted together, one of them being covered with rubber tubing as an additional precaution against leakage. Even with the heaviest currents (about 400 ampères) there was no effect on the instruments, and calibrations made both when the dynamos were and were not running, showed that any disturbance from currents in the leads had been avoïded.

Before any measurements were made, the insulation resistances between the leads themselves, and from the leads to the ground, were carefully tested and found in every case to be over fifty megohms; and measurements at intervals during the tests showed that they remained about the same.

OBSERVATIONS.

The power applied to the dynamos was measured by a Tatham dynamometer, while the electrical energy was calculated from observations of the potential at the terminals of the machine, the currents in the external circuit and field, and the resistance of the armature. The latter was measured by sending a current from a storage battery through the armature and observing the current in the circuit and fall of potential between the terminals of the machine.

The dynamos were run both on lamps and dead resistance, the value of the latter serving as a rough check on the potential and current.

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## APPARATUS.

*Storage Battery.*—This was kindly furnished by Mr. Weston, and was used for all calibrations, measurements of armature resistance, etc. Seventeen cells in series were generally employed; they were placed on boards separated from the floor by porcelain insulators.

Insert fold-out or map
Here

The storage battery, tangent galvanometer [illegible]

*Tangent Galvanometer.*—This was used for calibrating the current galvanometer. It consisted of a single turn of large-sized wire fastened on the edge of a wooden disk which was nailed against a square board frame. The ends of the wire were bent up parallel to each other and fastened by brass connectors to the leads. A correction due to the space between the ends of the turn was applied to the mean radius.

The diameter, about two metres, was measured in different directions, and the mean taken in calculating the constant.

There was a space cut in the middle of the wooden frame, with a shelf for the compass and needle. After the needle was adjusted to the centre and levelled, plumb lines and pointers were arranged so that any warping or change of level could be at once detected.

The value of $H$ was determined by a magnetometer of the Coast Survey pattern with detached theodolite ; it was found to be

$$\cdot 1938$$

and the constant of the galvanometer ;

$$31\cdot 088 \text{ ampères.}$$

*External Resistances of Dynamos.*—The "dead" resistances for the external circuit of the dynamos were made of german silver strips 1¼ inches wide by about ·01 inch thick. They were eight in number, each wound on a frame about 3 feet square by 10 feet high, made of four wooden uprights with pieces framed across at the top and bottom Porcelain insulators were fastened horizontally to the cross pieces and the resistances passed under one of the bottom insulators, over one at the top, to the bottom again, etc. Heavy copper wires were hard soldered to the ends of the strips and taken to the switch board.

The resistances were adjusted by cutting out part of the strip by a short length of german silver with clamps at the ends, which could be shifted to cut out as many of the turns as was desired. The coils were adjusted by means of a calibrated bridge, to 2·400 ohms at 20° C. There was a good air circulation in the room and fifty ampères could be carried by each coil.

In the same room with the german silver resistances were the racks for the incandescent lamps used for "live" resistances.

*Switch-Board.*—Two troughs about 2½ feet long and 1½ inches wide, and 10 inches apart, were cut in a heavy block of wood. Between them were bored two rows of eight holes each, and into these

were fitted glass insulators turned upside down to serve as mercury cups. The wood was soaked in boiling paraffine, and melted paraffine poured between the cups and allowed to harden. The distance between the troughs and the middle of the nearest row of cups was three and a-half inches; between the two rows, and the cups in each row, three inches. The cups and troughs were filled with mercury, heavy amalgamated copper rods in the latter serving to increase the conductivity. The resistances were brought to opposite cups in the two rows.

The dynamo circuit was from one terminal of the machine to an ordinary Edison switch, by which the current could be made or broken, to one of the troughs; through the resistance to the other trough; to the test house, passing through the fixed resistance for current measurement there; back by the other lead to the dynamo.

Connections at the switch board were made by thick U-shaped copper rods, with a stretch of three and one-half inches. The resistances could be readily arranged in any desired way, with little or no chance of causing accident by making mistakes. The insulation between the troughs and the cups and the troughs themselves was practically perfect.

*Field Galvanometer.*—The current in the field of the dynamos was measured by a tangent galvanometer of the Helmholtz type, the coils being each a single turn of large-sized wire. It was calibrated at the same time as the current galvanometer, being reversed as often as possible, and the same end of the needle read on each side of the zero mark.

*Wheatstone Bridge.*—For measuring resistances that could not be taken to the Johns Hopkins University, a resistance box, with a bridge attachment by Elliott, of London, was used, with a Thomson astatic mirror galvanometer. The box was standardized, as described below.

*Calorimeter.*—The calorimeter is shown in *Figs. 1 and 2.*

This was used for calibrating both the potential and current galvanometers; it was made of copper, was cylindrical in shape, about 8 inches in diameter by 10 inches in height, and held about eighteen pounds of water.

The cover was screwed to a flange on the cylinder, the joint being water-tight; in it were holes with raised flanges around

them, for the terminals of the coil and the thermometer. For stirring, a shaft, working in a bearing on the bottom of the cylinder and passing through the cover, had on it five paddles arranged along its length and at different angles around it, and bent to throw the water past the wire out to the side of the vessel. On reaching the side, a downward motion was given to it by strips of light copper, making an angle of about 30° with the vertical, soldered to the cylinder and projecting inward one and one-fourth inches. On the bottom of the shaft was a propeller blade. Putting saw-dust on the water and turning the shaft slowly showed the circulation to be excellent. Turning the wheel belted to the pulley on the shaft three times per second, raised the temperature of the calorimeter ·02° C. in five minutes. In the later experiments it was only turned once per second, so the error from this correction must have been small.

In the first three experiments, copper wire of about 1·3 ohms resistance was used; in the last two, platinum-silver wire of 1·1 ohms. The coil was held in the cylinder as follows: At equal distances around the cylinder, at the top and bottom, were soldered pieces of copper projecting inward, with clamps at their ends. The wire was wound on glass rods held in a light framework; the whole was placed in the cylinder, the rods clamped in place and the framework cut away, leaving a clear space for the stirring arrangement.

The terminals were small copper cups, thoroughly amalgamated and partly filled with mercury. They were surrounded by a rim of ebonite and wedged in their places in the cover.

The calorimeter fitted in a light iron frame, from which it was separated by small blocks of ebonite. The whole was surrounded by a tin cylinder fitting closely on the shelf to which the frame was fastened, so there was no draught past the cylinder.

*Balances.*—Two balances were used, one for weighing the calorimeter, the other in voltameter work. The former could weigh up to thirty pounds and was very sensitive. The latter was an excellent analytical balance. Both were by Trœmner, of Philadelphia, and the weights were compared with standards in his possession.

*Thermometers.*—The thermometers generally used were by Green, of New York. They were divided into degrees and tenths, and were compared at the Johns Hopkins University with one of the

standards there, the apparatus used in the comparison being that described by Professor Rowland, in his "Determination of the Mechanical Equivalent of Heat." * For the last two calorimeter experiments, a thermometer by Hicks, of London, was used. It was graduated to centimetres and millimetres, and was one of those used by Mr. Leibig, in his work "On the Variation of the Specific Heat of Water." †

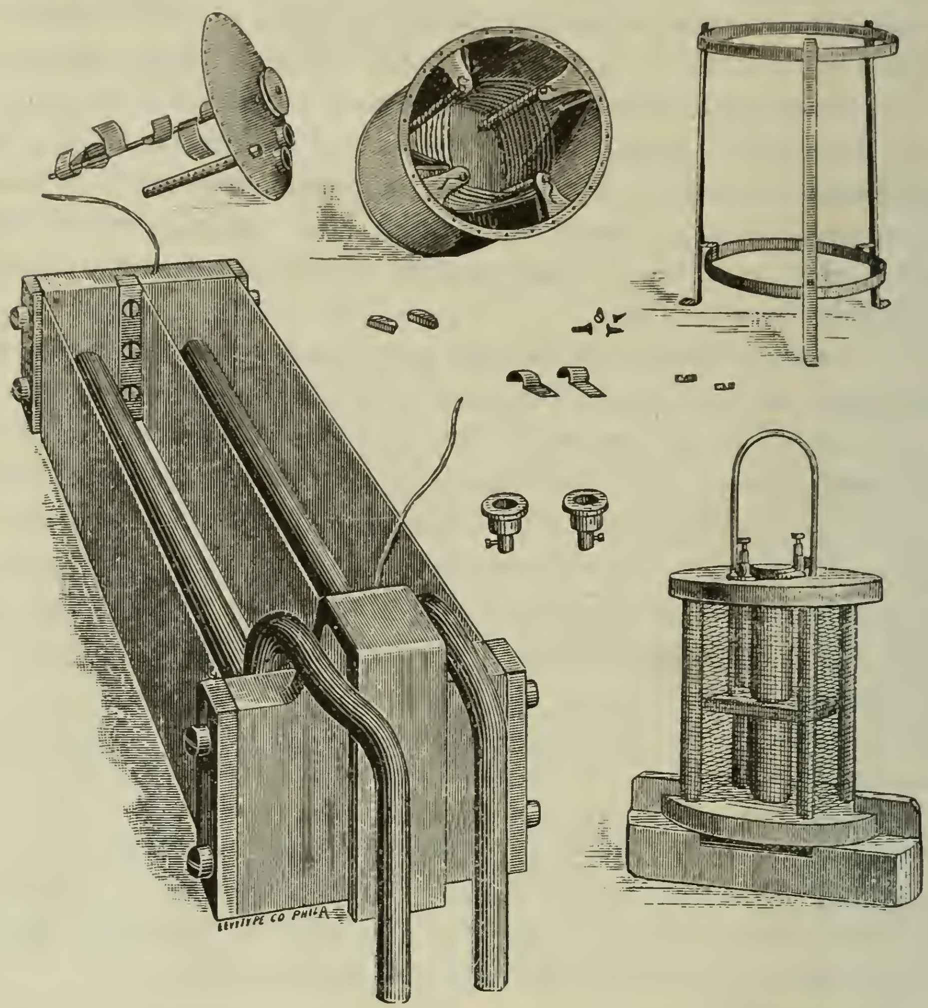

FIG. 1. (Calorimeter, Fixed Resistance and Potential Resistance.)

*Potential and Current Galvanometers.*—These will be described under measurements of potential and current. They, with the other instruments in the test house, rested on stone slabs cemented on the top of heavy wooden posts, sunk about two and one-half feet in the ground.

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* Proceedings of the American Academy of Arts and Science, 1880.

† American Journal of Science, July, 1883.

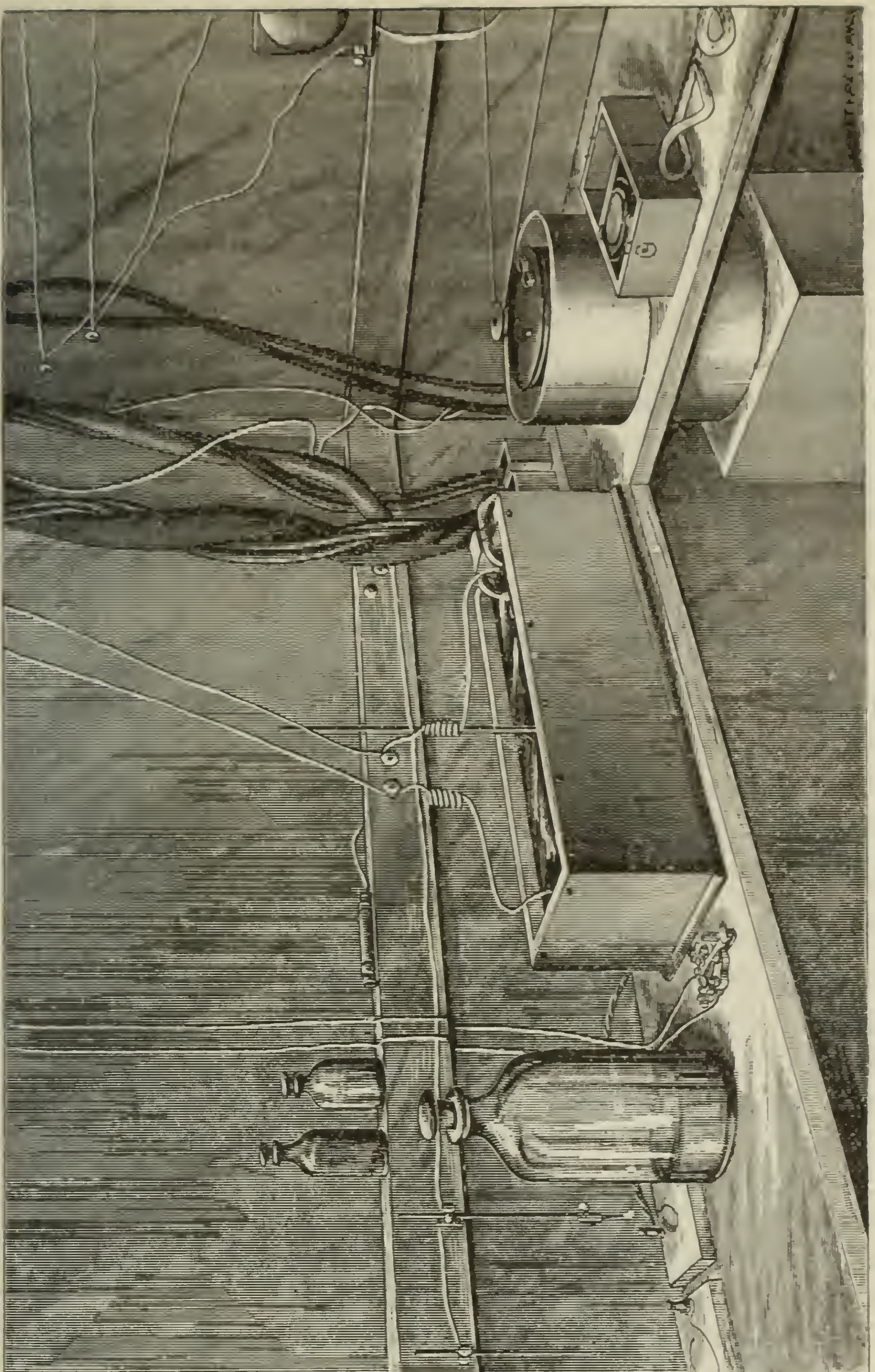

FIG. 2. (Test Room with Instruments in Position.)

# METHODS OF MEASUREMENT.

## MEASUREMENT OF RESISTANCE.

For the standard resistance, a ten B. A. unit coil by Elliott, which had been compared at the Cavendish laboratory, and was used by Professor Rowland in his recent determination of the ohm, was employed. The values of the resistances in terms of this coil were reduced to the Paris ohm, by dividing by

$$1{\cdot}0112.$$

The bridge used in the comparisons was built at the University Workshops, Cambridge, England. Its fixed (equal) arms were connected by a platinum-silver wire bent in a circle, and their ratio changed by making contact with the galvanometer circuit at different points on the wire. Beside the wire was a scale, and on the arm carrying the galvanometer contact, a vernier reading to tenths of a division. When the fixed coils were each one ohm, a whole division of the scale meant a change of one part in 10,000 of the ratio, while with the galvanometer used, a change of one-tenth of a division, or one part in 100,000 could be detected. The bridge had been calibrated for use in the determination of the ohm. With fixed coils of one ohm, the range of the instrument was about ten per cent, so the resistances to be compared were always approximately equal.

The different coils to be compared were balanced against resistances taken from "comparators," designed by Prof. Rowland. Each of these consists of ten coils of equal resistance wound together on a copper cylinder, the whole being coated with wax or paraffine and put inside a larger cylinder, the space between being filled with feathers. At the top, the cylinders are separated by an annular sheet of hard rubber, around which two circles of ten holes each are bored for the terminals. The ends of each coil are taken to copper blocks screwed firmly beneath opposite holes in the two circles. The tops of the copper blocks are thoroughly amalgamated and the holes partly filled with mercury, connections being made by short U-shaped copper rods.

Three comparators of ten, 100 and 1,000 ohms were used, giving a range of from one to 10,000 ohms.

Each coil of the ten-ohm comparator was balanced directly against the ten-ohm standard, then the ten coils in series were

balanced against each of the 100-ohm coils, and finally the 100-ohm comparator in series compared with each of the 1,000-ohm coils. In the measurements, the inner cylinders of the comparators were filled with water and the standard immersed in water, the temperatures being noted.

The zero of the bridge scale was taken as the mean of the readings when the resistances being measured were reversed.

In measuring the resistance boxes, they were kept for six or eight hours in a room whose temperature was nearly constant, and then balanced against corresponding resistances taken from the comparators, the temperatures being, of course, noted.

The coil for potential measurement was immersed in turpentine, its temperature recorded, and its resistance measured as above.

The resistances compared at the Johns Hopkins University were the box for current measurements, the coils and bridge for measuring resistance, and the coil for potential measurement.

### MEASUREMENT OF POTENTIAL.

THE GALVANOMETER used for potential measurements was by Hartmann. It was furnished with a Siemens' bell magnet, closely surrounded by a solid copper block, and damped very readily, only making two or three swings before coming to rest. The suspension was a silk fibre about fifteen centimetres long. The coils, specially wound over the regular winding of the instrument, had a resistance of about two ohms.

The galvanometer was in a circuit with resistances that were varied from 1,000 to 150,000 ohms, taken from boxes, two of 100,000, one of 10,000 ohms, the former by Elliott and Breguet, the latter by Bergman. All calibrations being made with the (30,000 + 20,000) Elliott coils in the circuit, it was necessary to compare the other resistances with these coils. The arms of the bridge being made equal, the (30,000 + 20,000) and (40,000 + 10,000) Elliott coils were balanced in succession against the 50,000 Breguet, resistances being added to one or the other until there was no deflection of the galvanometer. It was found that

50,000 Breguet = (30,000 + 20,000 + 280) Elliott.
50,000 Breguet = (40,000 + 10,000 + 250) Elliott.

The (30,000 + 20,000) ohms Elliott was also measured in terms of the bridge coils, and the value found, 49,960, was so nearly

correct that in getting the ratios of the 1,000 and 2,000 ohms Bergman—used in measuring armature resistance—to the (30,000 + 20,000) coils, it was assumed that their values in terms of the bridge coils were the same as if measured in terms of the (30,000 + 20,000) ohms.

The deflections were read by a telescope and scale, the latter by Brown and Sharpe, graduated to centimetres and millimetres. The distance from the telescope to the mirror was two and one-half metres.

*Calibrations.*—The galvanometer was calibrated, both by measuring a current passing through a standard resistance at whose terminals the leads of the instrument were connected; and by the difference of potential at the terminals of a calorimeter. The constant was also checked with that of the current galvanometer, after each test, by measuring the current through the german-silver strips used for the external circuit of the dynamos, and the potential at their extremities.

During the tests, forty calibrations were made; thirty-six with the silver voltameter and standard coil, and four with the calorimeter. The constants determined by the calorimeter agreed so closely with the measurements by the voltameter, and the labor both of observation and calculation in the former was so much greater than in the latter, that it was thought unnecessary to make the observation any oftener.

*Voltameter Calibrations.*—The current used varied from one to one and one-half ampères, giving a difference of potential at the terminals of the standard coils of from twenty to thirty volts. The coil shown in *Fig. 1* was of No. 22 german-silver wire, wound on glass rods fixed in a wooden framework. The turns were kept apart by silk cord wound on the rods. The whole was immersed in a high grade oil (300° fire test) kindly furnished by the Standard Oil Company. The oil was constantly stirred while the current was passing. The measurement of the resistance has been described. Its value was

21·161 ohms, at 14° C.

For measuring the currents, a silver voltameter was used, the anode being a spiral of silver wire wrapped in filter paper, the cathode a platinum crucible filled with a 40 per cent. solution of silver nitrate. The calibrations took from ten to twenty minutes, the deposit ranging from ·9 gram to 2· grams. The times were

noted by a chronometer whose rate, + 1 second per day, was neglected.

When the experiment was finished, the solution was poured out of the crucible; the deposit first washed with distilled water, then allowed to soak from one-half hour to twelve hours, then washed again until there was no precipitate with a solution of sodium chloride, and finally slowly dried and then weighed.

A double reading of the galvanometer was taken each minute, and the constant calculated from the mean reading for the time of observation. The constant is given by

$$k_{50} = \frac{C\,R\,(1 + M_c\,(t_c - 14°))}{2d}\left\{ 1 - M_b\,(t_b - 25°)\right\}$$

where

$k_{50}$ = constant for (30,000 + 20,000) ohms;
$R$ = resistance of standard coil at 14°;
$t_c$ = temperature of standard coil;
$M_c$ = temperature coefficient of standard coil;
$M_b$ = temperature coefficient of box;
$t_b$ = temperature of box;
$2d$ = double deflection of galvanometer;
25° being taken as the standard temperature of the box.

When other resistances were used in the circuit, the constant was multiplied by their ratio to the (30,000 + 20,000) ohms.

*Calorimeter Calibrations.*—The calorimeter has been described. In making the observations, the time the mercury crossed each half degree or centimetre of the thermometer was taken as the mean of the times of crossing the tenths before and after the division, and the division itself. In calculating the water equivalent of the calorimeter, the weight of the shaft was multiplied by the specific heat of steel; that of the cylinder by the specific heat of copper, and the weight of the glass and wire, by their specific heat. For steel, the value of the specific heat was assumed to be

$$\cdot 1110$$

and that of copper

$$\cdot 0940$$

The principal correction to be applied is due to radiation. The other corrections are for rise of temperature from stirring, for the

part of the thermometer stem in the air, and a small one for weighing in air.

The coefficient of radiation was determined by noting the rate of cooling, the calorimeter being slowly stirred. Experiments gave

| | | |
|---|---|---|
| Difference between air and calorimeter, | 10° C. 1 | coefficient, ·00154 |
| " " " " " | 5° C. | ·00150 |
| " " " " " | 0° C. | ·00149 |

Before the experiments, and for the determination of the radiation, the cylinder was carefully polished.

The correction for stirring was determined by bringing the calorimeter to exactly the temperature of the air, and then turning the wheel belted to the pulley on the shaft three times per second. The rise of temperature was ·02° in five minutes. For the smaller velocity used in the later experiments, the heating was assumed to vary as the cube of the velocity.

The correction for the temperature of the stem was taken from

$$c = \cdot 000156\, n\, (t - t'')$$

The following is one of the calibrations:

Calorimeter Observations. *Observers:* Anderson, Duncan, June 20th, 11·40 A. M.

| Time of passing ½ Centimetre. | Temperature of Calorimeter. | Temperature of Air. | Absolute Temperature of Calorimeter. | Thermometers. |
|---|---|---|---|---|
| | CM. | | | |
| 31–19·8 | 17·50 | 27· | 24·129 | For calorimeter, Hicks No. 108947. |
| 32–35·7 | 18· | 26·9 | 24·826 | For air, Green No. |
| 33–52·3 | 18·50 | 26·8 | 25·523 | |
| 35–08·3 | 19· | 26·9 | 26·221 | Water equivalent of calorimeter, corrected for weighing in air |
| 36–23·8 | 19·50 | 26·9 | 26·918 | |
| 37–41·3 | 20· | 27·0 | 27·618 | = 8·4311 kilos. |
| 38–56·7 | 20·50 | 27·3 | 28·316 | Value of mechanical equivalent used, (corrected for Latitude) |
| 40–14·2 | 21· | 27·4 | 29·015 | |
| 41–29·7 | 21·50 | 27·6 | 29·713 | = 425·75 |
| 42–46·2 | 22· | 27·7 | 30·411 | |

| Current: Wyckoff Observer. | | Potential: Murdock Observer. | |
|---|---|---|---|
| Deflection | Remarks. | Deflection | Remarks. |
| 17·56 | $R = 40$ | 10·27 | $R = 50,000$ |
| ·56 | $t_b$ 23·0 | ·26 | $t_b = 22°$ |
| ·53 | $t_s$ 22·4° | ·26 | |
| ·56 | $t_t$ 24·0 | ·26 | |
| ·54 | | ·25 | |
| ·56 | | ·27 | |
| ·54 | | ·26 | |
| ·53 | | ·24 | |
| ·51 | | ·28 | |
| ·48 | | ·26 | |
| ·50 | | ·27 | |
| ·47 | | ·29 | |

In making the calculations, Rowland's value of the mechanical equivalent was taken, because the thermometers used in the above experiment were compared directly with those employed by Prof. Rowland, and thus errors in thermometry were to a large extent eliminated. The following are the calculations for the observations:

| Interval. | Corresponding Interval in Degrees | Corresponding Interval of Time | | Degrees per Minute. | Same Corrected for Radiation. |
|---|---|---|---|---|---|
| centimetres. | | min. | sec. | | |
| 17·5 to 20· | 3·489 | 6 | 21·5 | ·5488 | ·5473 |
| 18 to 20·5 | 3·490 | 6 | 21·0 | ·5496 | ·5490 |
| 18·5 to 21· | 3·492 | 6 | 21·9 | ·5486 | ·5487 |
| 19 to 21·5 | 3·492 | 6 | 21·5 | ·5492 | ·5502 |
| 19·5 to 22· | 3·493 | 6 | 22·5 | ·5479 | ·5497 |
| | | | | Mean: | ·54898 |

| | |
|---|---|
| Rise per minute, | ·54898 |
| Correction for stirring, | — ·00044 |
| Correction for stem, | + ·00140 |
| Corrected rate, | ·54994 |

$$C^2 R \quad \log,\ 9{\cdot}517206$$
$$R \quad \log,\ 9{\cdot}038541$$
$$C^2 \quad \log,\ {\cdot}478665$$
$$C \quad \log,\ {\cdot}239332$$
$$K_c \quad {\cdot}02450$$
$$K_{50} \quad {\cdot}1847 \text{ @ } 22^\circ$$

Probably the greatest source of error in the calorimeter experiments was the superheating of the wire in the water. Using platinum-iridium wire varnished, with a smaller current than was generally employed in these experiments, Mr. L. B. Fletcher calculates* that the superheating is about 2° C. But in the measurements described above the wire was bare and the flow of water past it very much faster than in Mr. Fletcher's work. In the last two experiments a rise of 2° C. would cause an error of less than one-tenth per cent., so it is probable that they are not much affected by this source of error.

It is also possible that there was conduction through the water. The calorimeter was carefully cleaned before each experiment and distilled water used. If such an effect existed, it would be in an opposite direction from the superheating.

The usual range of temperature was 10° C.; in the experiment given it was a little over 6°.

Besides the regular calibrations, the constant was calculated after each test, from the potential at the extremities of the german silver "dead resistance," the current being measured by the current galvanometer, and the resistance measured by the bridge. The following partial list of calibrations excludes measurements made in this way. It includes the time during which most of the tests were made—from June 11th to June 23d:

* American Journal of Science, July, 1885.

| Date. | Value of $K_{50}$ | Constant Used. | Method. |
|---|---|---|---|
| June. | at 25 degrees. | at 25. | |
| 11 | 1·845 | 1·847 | Voltameter. |
| 11 | 1·8465 | 1·847 | Voltameter. |
| 12 | 1·847 | 1·847 | Voltameter. |
| 12 | 1·847 | 1·847 | Voltameter. |
| 13 | 1·844 | 1·844 | Voltameter. |
| 14 | 1·842 | 1·844 | Voltameter. |
| 16 | 1·843 | 1·844 | Voltameter. |
| 17 | 1·843 | 1·844 | Voltameter. |
| 18 | 1·845 | 1·844 | Voltameter. |
| 19 | 1·8434 | 1·843 | Calorimeter. |
| 19 | 1·844 | 1·843 | Voltameter. |
| 20 | 1·8485 | 1·843 | Calorimeter. |
| 22 | 1·843 | 1·843 | Voltameter. |
| 23 | 1·843 | 1·843 | Voltameter. |

For the Edison Nos. 5 and 10 dynamos, the potential galvanometer was in the same position as when used for the duration test of lamps, in a room at some distance from the test house. The constant as determined during the tests of these machines agreed closely with that used in the duration tests, which had but just ended. But when the instrument was removed to the test house, the constant began to vary, changing greatly from day to day, with sometimes a sharp change during the day. The Weston No. 7 M dynamo was tested on full load with the constant in this unsatisfactory state, and between the second and third tests there was a change of over one per cent. Although the number of calibrations made these measurements perfectly trustworthy, yet the labor and anxiety were both too great to be repeated with each test.

So before the machine was run on the partial loads, the galvanometer was taken to pieces, the coils rewound and soaked in paraffine, and the stand of the tube carrying the suspension more firmly secured. A beam, which pressed against the wooden pier, was also cut away. After this, the constant did not vary, the calibrations rarely differing more than one-tenth per cent. from the constant used.

MEASUREMENT OF CURRENT.

The currents were measured by observing the ratio of the potentials at the ends of a fixed resistance when a known current and the current to be measured were passing respectively. To do this, the terminals of a circuit containing a galvanometer and a resistance box were permanently fastened to the extremities of the fixed resistance. A current was sent through the latter, and the resistance of the box adjusted until the proper deflection of the galvanometer was obtained; the current was measured by the voltameter, tangent galvanometer, or calorimeter, and the deflection and resistance were observed. When any other current was to be measured, the box was changed until the deflection was about the same as before, and both the deflection and resistance noted. The thermometers used in getting the temperatures of the different parts of the circuit were those by Green, already described.

The notation and formulæ used are as follows:

Let $C'$ be the current used in calibration;
$r'$ be the resistance used in calibration;
$d'$ be the deflection used in calibration;
$t'_s$ be the temperature of fixed resistance at calibration;
$t'_b$ be the temperature of resistance box at calibration;
$t'_g$ be the temperature of galvanometer at calibration;
$C''$ be the current to be measured;
$r''$ be the corresponding resistance;
$d''$ be the corresponding deflection;
$t''_s$ be the corresponding temperature of fixed resistance;
$t''_b$ be the corresponding temperature of the box;
$t''_g$ be the corresponding temperature of galvanometer;
$t_o$ be the standard temperature $= 25°$ C.;
$u_g$ be the temperature coefficient for galvanometer circuit;
$u_s$ be the temperature coefficient for fixed resistance and box;
$G$ be the galvanometer resistance;
$k$ be the constant at 25° C.

Then

$$k = \frac{C'}{2d'} \, \frac{1 + u_s\,(t'_s - t_o)}{\left[\; G\,\{1 + u_g\,(t'_g - t_o)\} + r'\,\{1 + u_s\,(t'_b - t_o)\}\;\right]}$$

$$C'' = k\ 2d'' \left[1 - u_s\,(t''_s - t_o)\right] \quad \left[G\,(1 + u_g\,(t''_g - t_o)) + r''\,(1 + u_s\,(t''_b - t_o))\right]$$

Calculations were facilitated by making tables of

$$G\,\{1 + u_g\,(t_g - t_o)\}$$

for the different temperatures, of

$$r\,\{1 + u_s\,(t_b - t_o)\}$$

for the different resistances that were to be used, and of

$$1 - u_s\,(t_s - t_o)$$

for the different temperatures of the fixed resistance.

*Galvanometer.* — A mirror galvanometer, by Edelmann, of Munich, was used. It was furnished with a ring magnet damped by surrounding copper blocks. The suspension, originally about two feet long, was shortened to about seven or eight inches by a copper rod passing inside the glass suspension tube; there was no trouble from vibrations. The coils were movable on graduated bars, but for the tests they were clamped and their position never changed. The resistance of the coils, with the fixed resistance and the leads to it, was

·3973 ohms, at 25°.

This was taken as $G$ in the formulæ, and the temperature coefficient for copper used; the value of the german silver fixed resistance being only about ·0004 ohms, and the rest of the circuit being copper. The galvanometer was read with a mirror and scale, the latter being of porcelain, graduated to centimetres and millimetres. The distance from the galvanometer was 2·5 metres.

*Resistance Box.*—The resistance box, by Hartmann, being open at both ends and having no paraffine on the coils, was very well fitted for its work. Its measurement has been described.

*Fixed Resistance* —The details of the fixed resistance are shown in *Figs. 3, 4 and 5*, which are respectively, a plan, side elevation, and end view. It is also shown in perspective in *Figs. 1 and 2.* It consisted of three strips of german silver, 4½ inches broad by ·036 inches thick, the ends hard-soldered into heavy copper blocks.

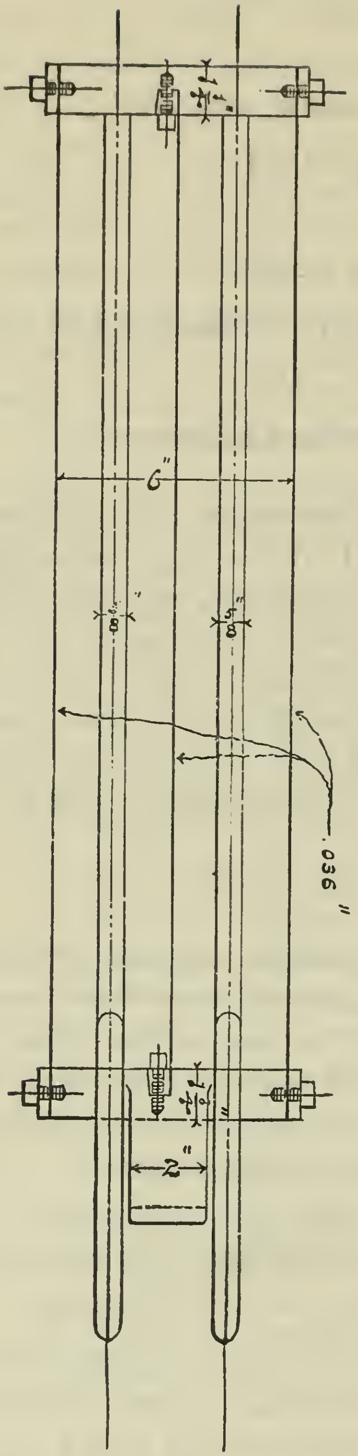


FIG. 3. (Plan.)

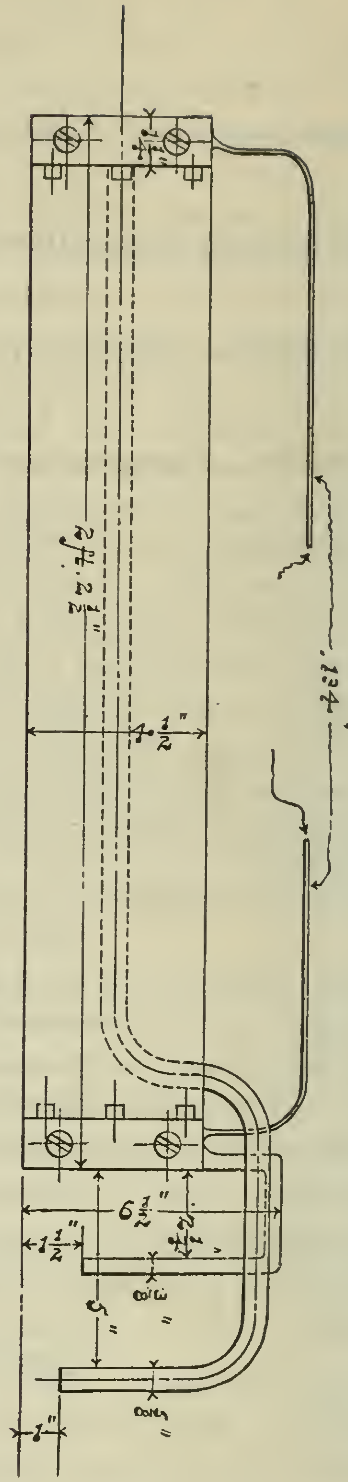


FIG. 4. (Side elevation.)

One of the blocks had a terminal piece cast on it that was bent to clear the edge of the tank in which the resistance was placed, and dipped into a mercury cup, to which one of the main leads was brought. From the other block, two copper rods passing between the strips, were bent over the edge of the tank and dipped with the other main lead into another mercury cup. The terminals of the galvanometer circuit were soldered into the copper blocks and remained permanent during the tests. The whole was put in a rectangular tank filled with the same kind of oil as was used for the potential resistance.

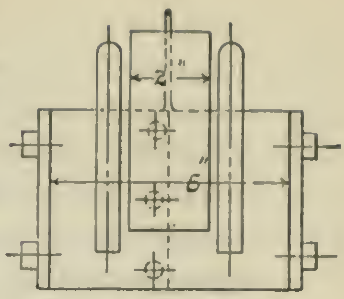

FIG. 5. (End view.)

*Calibrations.*—Calibrations were made by sending a current through the fixed resistance, measuring it, observing the deflection of the galvanometer and the resistance in its circuit, and noting the temperatures. The calibrations usually lasted ten minutes. The constant was calculated by the formula already given.

Three methods of measuring current were used; the silver voltameter, tangent galvanometer and calorimeter.

For the voltameter calibrations, a large platinum dish was used as cathode, a flattened spiral of silver wire wrapped with filter paper as anode, while a forty to fifty per cent. solution of silver nitrate was employed. With this strength of solution and with the usual current, about four ampères, the deposit was very regular and beautiful. It was treated as described under potential measurements. The resistance in the circuit was about ten ohms.

The tangent galvanometer has been already described. Two observers read both ends of the needle on each side of the zero mark. The current was reversed every minute; it varied from twenty to thirty ampères.

The method of using the calorimeter has been described The observations give $C^2 R$, and $R$ being measured by the bridge, $C$ may be found, with the advantage that errors of observation are halved in the value of $C$.

Altogether, there were five calibrations by the tangent, nine by the voltameter and five by the calorimeter. The following are the values obtained:

·024510 by voltameter.
·024510 by voltameter.
·024440 by tangent galvanometer.
·024550 by tangent galvanometer.
·024510 by voltameter.
·024480 by voltameter.
·024590 by tangent.
by calorimeter.
·02455 by tangent.
·02455 by voltameter.
·024481 by calorimeter.
·024477 by calorimeter.
·024520 by tangent.
·024500 by voltameter.
·024516 by voltameter
·02453 by calorimeter.
·024495 by voltameter.
·024494 by voltameter.
·02450 by calorimeter.

THIS PRINCIPLE of measuring current has been used before, notably at the Vienna and Munich Exhibitions, but as employed in the following tests the method differs from that previously used in an important particular, *i. e.*, the construction of the fixed resistance. The substitution in the fixed resistance of german silver strips in oil instead of the copper bars in air formerly employed, increased greatly both the range and accuracy of the method.

As the method has not been commonly used, and is possibly not very generally understood, a brief discussion of the sources of error and their probable value in these tests will be given.

The possible sources of error are :

(1.) In observing the deflections ;
(2.) In the constant ;
(3.) In the temperature correction for fixed resistance ;
(4.) In the temperature correction for resistance box ;
(5.) In the temperature correction for galvanometer ;
(6.) In the values of the coils in the box ;
(7.) In the resistance of the galvanometer coils ;
(8.) In assuming the currents proportional to $2d$.

(*1*) Error in observing the deflections.

This error would enter directly in the result. The scale could be read with considerable accuracy to tenths of millimetres; the double deflections were usually between twenty and thirty centimetres. The currents measured were quite steady, but even if they varied, the excellent damping of the galvanometer would allow the readings to be taken with a good deal of precision.

(*2.*) Errors in the constant.

On looking at the table of constants, it will be seen that the results obtained with different resistances in the galvanometer circuit, different currents, temperatures and deflections, and by entirely independent methods of measuring current, agree so closely that their mean must be very near the true constant. Two of them, exceptional ones, differ from the mean by one-third per cent., a few more by one-sixth per cent., but the greater number are within one-tenth per cent. of the constant used. Double weight was given the voltameter calibration, as involving less possibility of error than the other methods; with two exceptions, they are within one-fifteenth per cent. of the mean. Any error would enter directly.

(*3.*) Errors in the temperature correction of the fixed resistance.

The uncertainty due to the temperature correction of the fixed resistance must have been inappreciable. Its temperature coefficient was small, about one-tenth that of copper, while its temperature, considering the large surface of very thin metal exposed to the liquid, must have been quite accurately known. For the heavier currents, the oil was constantly stirred. With about 400 ampères in the circuit, the thermometer registered $\cdot 1^\circ$ C. more when held against the strip than when in the body of the liquid; while the oil rose $1\cdot 5^\circ$ during the test. To further decrease the possibility of error, the oil was kept within at the most $5^\circ$ or $6^\circ$ of the usual temperature of calibration by cooling it when necessary between the tests. An error would enter directly in the results.

(*4.*) Errors in the temperature correction of the resistance box.

Both ends of the box were open to the air and the coils were not coated with paraffine. The bulb of the thermometer lay against or very near the coil in use. The currents could cause no appreciable heating and the temperature of the room changed slowly.

The temperature coefficient was taken as

$$\cdot 0004,$$

and calibrations made at different temperatures showed that this was not much in error. Errors would enter almost directly in the result.

(*5*.) Errors in the temperature correction of the galvanometer coils.

The temperature of the galvanometer coils was given by a thermometer hung near them. With the smallest resistance used, any error in this correction would only enter as one twenty-fifth in the result.

(*6*.) Errors in the values of the coils in the resistance box.

The measurement of the resistance box has been described. The values were probably correct within one part in 2,000 or 3,000. Any error would enter directly in the result.

(*7*.) Errors in the resistance of the galvanometer circuit.

The resistance of the galvanometer and its circuit was measured by the standardized bridge. The error was probably small and entered at the most as one twenty-fifth in the result.

(*8*.) Error in assuming the currents proportional to $2d$.

This error is slight and was to a large extent eliminated by making the calibration on about the same part of the scale as the measurements.

The only errors then that would be appreciable are in the deflections, the constant, the temperature correction of the box, and the values of the resistance coils. The last of these could hardly have been over one-twentieth per cent.; the temperature correction of the box was probably within one-tenth per cent.

This method has several advantages. The range is very great (with the apparatus described currents of from two or three ampères to 400 could be measured with about the same accuracy) while the errors are not multiplied in the result and are of such a nature that with proper precautions many of them can be almost entirely eliminated, and the rest made very small.

Although in measurements of both potential and current any change in $H$ would directly affect the results, yet as certainly two

and usually more voltameter calibrations were made for each day of the tests, and the constants were checked after each measurement, it is not probable that any important error arose from this cause.

It is also interesting to note that the magnetometer records that showed such irregularities during the life test of lamps* just finished, were remarkably uniform during the dynamo tests.

## POWER MEASUREMENTS.

THE general principle of the Tatham dynamometer is shown in *Fig. 6*. The power applied to the shaft on which the driving pulley *D* is fixed, is transmitted to the pulley *B*, to whose shaft the machine to be tested is coupled, by an endless belt, which passes

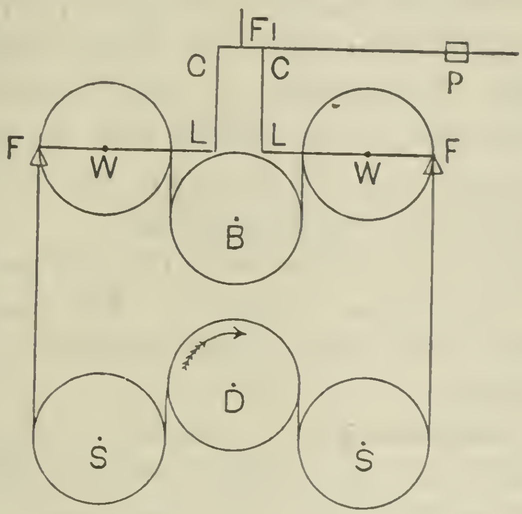


FIG. 6.

over *D*, under the stretching pulley *S*, over the weighing pulley *W*, under *B*, over the second weighing pulley *W*, under *S*, back to the place of starting. Each of the weighing pulleys *W* is supported in a cradle, the outer end of which is pivoted on the knife edge *F*, while the inner end is supported by the link *L C*. The upper ends of the two links are fastened to the scale beam *F*, *P* at equal distances from and on either side of the fulcrum *F*.

To calculate the power applied to the pulley *B*, it is necessary to know three things: The difference of tension of the belt on the two sides of *B*; its effective diameter, and its number of revolutions. These will be discussed in order.

The scale beam is acted upon through the links *L C*, fastened

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* JOURNAL FRANKLIN INSTITUTE, Sept., 1885.

to the cradles of the weighing pulleys *W*. The tensions of the belt on the outer faces of these pulleys have no effect on the beam, since the line of effort of the belt passes through the knife edges *F*. The only forces then that act on the beam are the two tensions of the belt on the inner faces of the pulleys *W*, *and these are the tensions on the two sides of B ;* and the links being at equal distances on either side of *F*, the *difference of the tensions* is recorded on the beam.

The scale beam was of steel, graduated by Brown and Sharpe into 600 divisions. With the weight used each division meant one-half pound. A small poise travelling on the weight allowed readings to be taken to $\frac{1}{200}$th of a pound.

There were two adjustments to the cradles. In the first, the axis of the pulley *W* was moved by micrometer screws to such a position that the line of effort of the belt passed through the knife edges of the cradle. To show this, the pulley was chocked, a short piece of the belting hung on its outside face, and weights placed in a pan hanging to the belt. When there was no effect on the scale beam, the adjustment was accomplished.

The second adjustment determined the position of the knife edge to which the links were connected. This was moved until the beam weighed about 250 pounds correctly to within one-twentieth of a pound.

The pulley *B* was calculated to deliver 6·6 feet per revolution, but the belting used was thicker than was at first intended, and the value 6·6 should be increased by one-fourth per cent. The effective diameter of the pulley, including the thickness of the belt, was measured directly, and also calculated from the length of belt delivered by five turns of the pulley. For the latter measurement, two steel points, one of which was fitted with a micrometer screw, were fixed on a wooden rule, and their distance apart accurately determined on a standard scale. Marks were made on both the pulley and belt opposite to fixed pointers. Five revolutions were given the pulley, and the length of belt that passed the pointer was measured by the rule with the steel points, any margin being taken off by a pair of compasses. The pulley was turned both ways and the effect of stretching eliminated.

The two methods checked very closely, and gave for the delivery of the pulley

$$6{\cdot}6\ (1{\cdot}0025)\ \text{feet per revolution.}$$

A very ingenious mechanical counter registered the number of revolutions. Observations could be taken each minute, and the counter recorded continuously to 1,000,000 revolutions.

Having the difference of tension on the two sides of *B*, its delivery per turn, and number of turns per minute, the horse-power is calculated as follows:

$$\text{Horse-power} = \text{divs. scale beam} \times \text{no. revs.} \times \frac{6.6\,(1.0025)}{2 \times 33000}$$

$$\text{Horse-power} = 1{\cdot}0025 \left\{ \frac{\text{divs. scale beam} \times \text{no. turns per min.}}{10{,}000} \right\}$$

It will be seen that the only part of the friction of the dynamometer that appears in the readings, is that due to the bearings of the pulley *B*. By the principle of Morin, that the sum of the tensions on the two parts of a belt is constant, this friction should be the same whatever the load. In getting the power applied to a machine, after the measurements have been made with the machine coupled to the dynamometer, it was uncoupled and the dynamometer run at the same number of revolutions, the scale beam observed, and its reading subtracted from the reading when coupled.

To avoid the uncertainty of loss due to belting, the shaft of the driven pulley *B* was coupled directly to the dynamo by a universal coupling, as shown in *Fig*. 7. It was assumed that this would allow for any slight inexactitude in lining the dynamo and dynamometer shafts, but it is doubtful if it was of much value at the high speeds used for the tests.

The figure of the dynamometer (*See Frontispiece*) gives a view of it as used in these tests. The automatic recorder for the scale beam, shown in the figure, was not used. In making observations, the number of revolutions and scale beam were read each minute, usually for ten minutes. The means of the two sets were multiplied together, the product divided by 10,000, and a correction of one-fourth per cent. applied, as given in the formula.

The delicacy and range of the dynamometer were both very great. On one occasion the power absorbed by a single Weston mammoth lamp was accurately measured, while the slightest variation of the load could be at once detected. During a test, the scale beam usually floated steadily, the slight and rapid jar caused

by running served to limber up the weighing apparatus and render it especially sensitive. Indeed, it would be hard to fix a limit to the accuracy with which the observations could be taken.

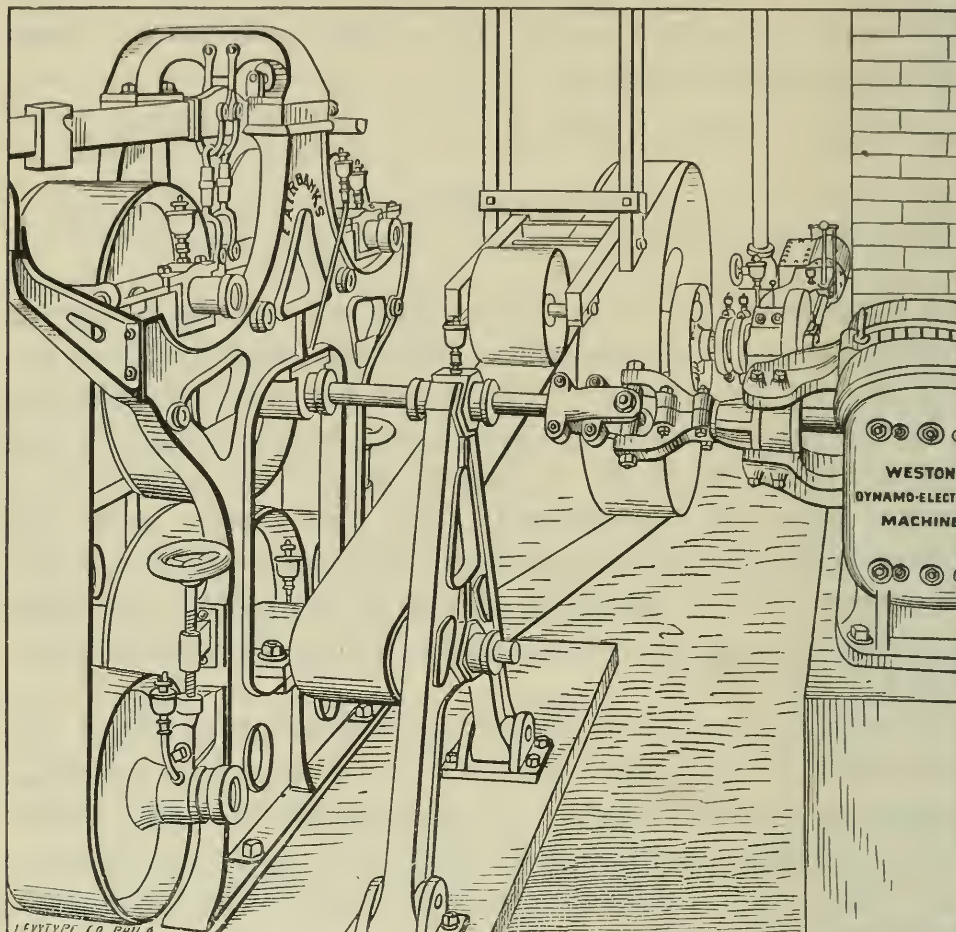


FIG. 7.—Universal Coupling.

Mr. Tatham has published a paper,* giving the principles involved in the dynamometer, and describing its various modifications of form.

The engine used was a 10″ x 20″ Salem Buckeye. Its governor adjustment could be readily varied from 100 to 200 revolutions. The speed, under the steady load of a dynamo, was very uniform.

A steel boiler, loaned by the Baldwin Locomotive Works, was used. It could safely carry 150 pounds per square inch and develop eighty horse-power.

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* JOURNAL FRANKLIN INSTITUTE, Dec., 1882. Vol. cxiv.

CHECKING THE DYNAMOMETER.

IN ORDER to make the tests absolutely, as well as relatively accurate, it was decided to check the work recorded by the dynamometer against an amount of work calculated from the mechanical equivalent of heat.

To do this, a calorimeter was constructed, the general plan of which is shown in side and end section in *Figs. 8* and *9*.

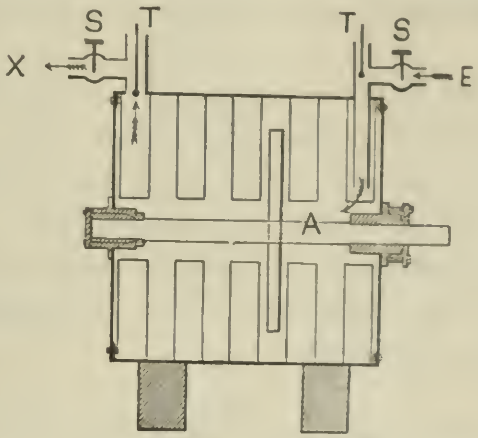


FIG. 8.

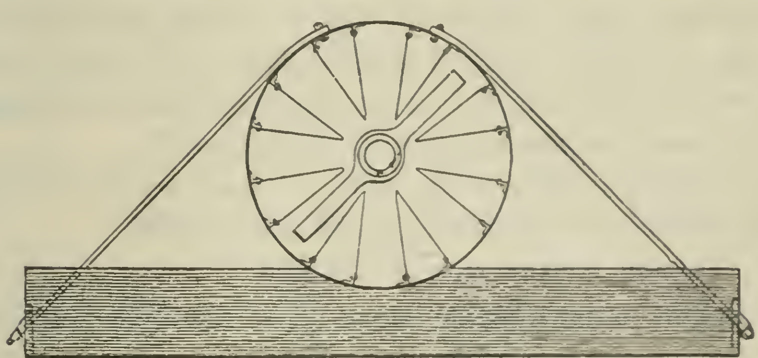

FIG. 9.

It was of wrought iron, 3 feet long by 3 feet in diameter, with V-shaped projections riveted inside the shell. The paddles, 30 inches long by ½ inch thick, were keyed to the shaft and moved between the V's. One end of the shaft passed through the end of the calorimeter, and was coupled to the dynamometer. In the experiments but one paddle was used, 700 revolutions absorbing about forty-five horse-power.

Two different methods of experiment were employed; first, with a constant weight of water and an increasing temperature;

and second, with a constant temperature and a continuous flow of water through the calorimeter.

*First Method.*—In the first method, the calorimeter was filled and its water equivalent found, the engine was then started, and the rise of temperature noted and the dynamometer observed. The mechanical equivalent was calculated from the work recorded by the dynamometer, the water equivalent of the calorimeter and the rise of temperature, the necessary corrections being applied to the latter. The value thus obtained was compared with the values of Joule and Rowland.

In getting the water equivalent, the calorimeter was first weighed empty and then when filled with water. The difference gave the weight of the water, and the water equivalent of the iron was calculated from its weight and specific heat. It was intended to determine by experiment the specific heat of the specimens of the iron used in the calorimeter, but circumstances made this impossible. The value used,

$$\cdot 112,$$

is taken from determinations by Bystrom, Weinhold, Regnault and Bede, reduced to 30° C. The values given by these different experimenters agree very well, and it seems probable that the mean does not differ from the specific heat of the iron used in the calorimeter by more than one or two per cent. at the most—an error that enters as about one-tenth in the result.

The weighings were made with a scale beam by Fairbanks. Both the weights and graduation had been tested.

The following are the results obtained:

| | |
|---|---|
| Weight of calorimeter alone, | 1228·75 pounds. |
| Weight of calorimeter with water, | 2451·75 pounds. |
| Weight of water, | 1223·0 pounds. |
| Water equivalent of the iron, | 137·62 pounds. |
| Total water equivalent, | 1360·62 pounds. |
| Correction for weighing in air, | 1·38 pounds. |
| Water equivalent, corrected, | 1362·00 pounds. |

*Temperature Observations.*—The thermometers used were those by Green, already described. The time the mercury crossed each half degree was observed and was taken as the mean of the times of crossing the tenths below and above the division, and the division itself. The times were noted by a chronometer.

The following table gives the temperature observations and the dynamometer readings,—the latter were taken each minute :

*Calorimeter Observations for Checking Dynamometer, June 27.*

| Temperature. | Observed Time of Crossing Division. | Corrected Time of Crossing Division. | Intervals for 4·5° C. | Remarks. |
|---|---|---|---|---|
| 30·5 | 12-01-44· | 12-01-44· | | The times were corrected arbitrarily by the observations on either side. |
| 31· | 02-20·3 | 02-20·3 | | |
| 31·5 | 02-57·0 | 02-56·8 | | |
| 32· | 03-33·3 | 03-33·3 | | |
| 32·5 | 04-09·6 | 04-09·7 | | |
| 33· | 04-46·0 | 04-46·3 | | |
| 33·5 | 05-22·3 | 05-23·1 | | |
| 34· | 06- 1·6* | 06-00·2 | | |
| 34·5 | 06-37·6 | 06-37·3 | | |
| 35· | 07-14·0 | 07-14·4 | 5-30·4 | |
| 35·5 | 07-51·6 | 07-51·6 | 5-31·3 | |
| 36· | 08-29·0 | 08-29·0 | 5-32·2 | |
| 36·5 | 09-07·3 | 09-06·2 | 5-32·9 | |
| 37· | 09-43·3 | 09-43·4 | 5-33·7 | |
| 37·5 | 10-20·3 | 10-20·6 | 5-34·3 | |
| 38· | 10-58·0 | 10-58·0 | 5-34·9 | |
| 38·5 | 11-36·0 | 11-35·5 | 5-35·3 | |
| 39· | 12-13·0 | 12-13·0 | 5-35·7 | |

*Untrustworthy, only one reading.

*Dynamometer Readings.*

| Time. | Counter. | Scale Beam | Friction. | Remarks. |
|---|---|---|---|---|
| 12-01-00 | 0159 | | | |
| 02-00 | 0881 | 665 | 13·72 | |
| 03-00 | 1603 | 666 | 13·72 | |
| 04-00 | 2326 | 664 | 13·72 | |
| 05-00 | 3042 | 661 | 13·72 | |
| 06-00 | 3761 | 661 | 13·72 | |
| 07-00 | 4479 | 661 | 13·72 | |
| 08-00 | 5198 | 663 | 13·72 | |
| 09-00 | 5916 | 666 | 13·72 | |
| 10-00 | 6640 | 666 | 13·72 | |
| 11-00 | 7360 | 666 | 13·72 | |
| Mean : | 720·1 | 663·9 | 13·72 | |

The corrections to be applied to the thermometer readings are for the part of the stem in the air, and for radiation. The first of these is somewhat indefinite, as a portion of the stem is heated

by conduction from the calorimeter. The whole correction, however, is only about one-third per cent., and its value is probably correct within twenty or thirty per cent. so the error in the result from this cause can hardly be much over one-tenth per cent.

But the most important correction, and the one in which there seems the greatest possibility of error, is the coefficient of radiation. This is usually determined by slowly stirring the calorimeter, and noting its difference of temperature from the air and rate of cooling, correcting for the heat developed in stirring. But with a single thin blade, and no arrangement for causing circulation, this method was impracticable. In some experiments that were tried, the water was not thoroughly mixed, and the cool water falling and warm water coming to the top, made the values obtained worthless.

Under these circumstances, it became necessary to calculate the radiation from the experiment for the determination of the mechanical equivalent.

The method of calculation was as follows: The observations were divided into intervals of 4·5° C., as shown in the following table, and the corresponding intervals of time were reduced to the same rate of doing work, the same value of the specific heat of water, and the same value for the stem correction of the thermometer. The remaining difference in the intervals is assumed to be due to radiation.

*Calculation of Radiation.*

| INTERVAL. | Time Interval Uncorrected | Ratio of Rate of Doing Work to Mean Rate. | Correction for Specific Heat of Water.* | Correction for Stem in Air.* | Time Interval Corrected. | Excess over First Interval. |
|---|---|---|---|---|---|---|
| degrees. | minutes. | × | ÷ | ÷ | minutes. | minutes. |
| 30·5—35· | 5·5067 | 1·00145 | 1·00000 | 1·00000 | 5·51467 | ·00000 |
| 31· —35·5 | 5·5217 | 1·00026 | 1·00000 | 1·00016 | 5·52224 | ·00757 |
| 31·5—36· | 5·5367 | ·99957 | 1·00010 | 1·00032 | 5·53200 | ·01733 |
| 32· —36·5 | 5·5483 | ·99885 | 1·00020 | 1·00048 | 5·54196 | ·02729 |
| 32·5—37· | 5·5617 | ·99847 | 1·00031 | 1·00065 | 5·54808 | ·03341 |
| 33· —37·5 | 5·5717 | ·99824 | 1·00040 | 1·00081 | 5·55530 | ·04063 |
| 33·5—38·0 | 5·5817 | ·99980 | 1·00050 | 1·00097 | 5·57250 | ·05783 |
| 34· —38·5 | 5·5883 | 1·00134 | 1·00060 | 1·00113 | 5·58607 | ·07140 |
| 34·5—39· | 5·5950 | 1·00219 | 1·00070 | 1·00130 | 5·59600 | ·08133 |

Gives radiation ·00258° per degree per minute.

* These are the ratios of each succeeding interval to the first interval.

The differences of these corrected intervals from the first interval were plotted, the excess of the mean temperatures of the intervals over that of the air being taken as abscissæ, and the above differences as ordinates. A straight line was drawn through the points thus found. The radiation was calculated by taking the difference of the ordinates for an interval of 4°, and from this value (which is the loss of time due to radiation, in an interval of about 5·55 minutes, the difference of temperature being 4°), the coefficient of radiation was easily found.

In drawing a straight line through the points, we have assumed the coefficient of radiation to be constant when the excess of temperature over that of the air varies, instead of increasing with the excess. Within the rather narrow limits of temperature used, however, the value found represents very nearly the radiation for the mean interval. In calculating the experiment by the second method, the value of the radiation found above was corrected to the greater difference of temperature between the calorimeter and air, by increasing it in the ratio shown by the experiments of McFarlane and Rowland

This method of calculating the radiation, while not so accurate as the method usually employed, has the advantage that the conditions of observation are accurately those of the experiment to which the radiation is applied.

It will be seen that the errors likely to affect the radiation coefficient, are errors of observation, in the relative values of the specific heat of water at the different temperatures, and in the ratios of the stem corrections.

As for errors of observation, the dynamometer readings for the intervals were the mean of five observations, and, although the jar interfered somewhat with the readings of the thermometer, yet the table shows that there were no very great errors, and the method of observation allowed the readings to be to some extent corrected by those on either side.

The ratios of the values of the specific heat of water for the different intervals were calculated from Rowland's values of the mechanical equivalent for the mean temperatures of the intervals. Fortunately the correction was small, and probably accurately given.

Whatever the absolute value of the stem correction might have

been, there could be little error in the relative values for the different intervals.

The result obtained was:

| | |
|---|---|
| Excess of cal. over air, 4° C. | coefficient of radiation, ·00258 |
| 8° C. | ·00262 |

On applying the above values to the observation by the first method, we obtain:

| | |
|---|---|
| Mean rise of temperature, per minute (uncorrected) | ·809814 |
| Mean correction for radiation, | + ·017790 |
| Mean correction for stem, | + ·003034 |
| Mean correction to absolute temperature, | — ·001350 |
| Mean rise, per minute (corrected) | ·822288 |
| Water equivalent of calorimeter, | 1362·0 pounds. |
| Heat units developed, per minute, | 1119·9562 |
| Mean reading scale beam, | 663·9 |
| Friction reading scale beam, | 13·72 |
| Difference reading scale beam, | 650·18 |
| Mean revolutions, | 720·1 |
| Work in foot pounds = product × 3·3 × 1·0025 | 15489048 |
| Mechanical equivalent for 1° C, | 1383·01 ft. lbs. |
| Mechanical equivalent for 1° F., | 768·34 ft. lbs. |

Unfortunately, however, the construction of the calorimeter made the results of this experiment untrustworthy. The blades were kept apart by pieces of 4-inch pipe, ⅛ inch thick, fitting over the shaft between them. In the space between the shaft and pipe were about five pounds of water not in circulation with the mass in the calorimeter. The shaft being jacketted with this layer of water, must have gained heat but slowly. The result was that the heat units calculated were too great, and the mechanical equivalent too small. It is also probable that this effect would make the coefficient of radiation calculated from this experiment slightly too large.

We can only say of this experiment then that the value is

768·3 + an indeterminate correction.

*Second Method.*—In this method water was made to flow continuously through the calorimeter. The engine was run until the temperature of the exit water ceased to rise, and then observations of the entrance and exit temperatures and of the dynamometer were taken each minute, and the exit water weighed every four minutes. The weighings were made by two of Fairbanks' platform scales that had been tested with standard weights. The observations lasted one and one-half hours. The heat units were calculated for each interval of four minutes, as shown in the table, and their sum taken for the whole interval. The scale reading and number of revolutions of the dynamometer were averaged for the time of the experiment, the work being calculated from the means (Philadelphia time).

*Continuous Calibration.—Tatham Dynamometer, June 27, 1885.*

| Time. | Mean Temperature Exit. | Mean Temperature Entrance | Increase. | Weight $H_2O$ | Heat Units. |
|---|---|---|---|---|---|
| 11·02 | | | | | |
| ·06 | 39·528 | 23·82 | 15·708 | 287·25 | 4512·123 |
| ·10 | 39·5975 | 23·8225 | 15·775 | 267·00 | 4211·925 |
| ·14 | 39·65 | 23·8125 | 15·8375 | 261·25 | 4137·546875 |
| ·18·30 | 39·7125 | 23·815 | 15·8975 | 293·75 | 4669·890625 |
| ·22 | 39·7025 | 23·82 | 15·8825 | 235·00 | 3732·3875 |
| ·26·30 | 39·67 | 23·8025 | 15·8675 | 310·50 | 4926·85875 |
| ·30 | 39·645 | 23·80 | 15·845 | 228·75 | 3624·54375 |
| ·34 | 39·6125 | 23·80 | 15·8125 | 271·25 | 4289·140625 |
| ·38 | 39·6150 | 23·805 | 15·810 | 274·00 | 4331·94 |
| ·42 | 39·5875 | 23·8025 | 15·785 | 270·75 | 4273·78875 |
| ·46 | 39·5875 | 23·8275 | 15·76 | 274·00 | 4318·24 |
| ·50 | 39·5375 | 23·845 | 15·6925 | 276·00 | 4331·13 |
| ·54 | 39·52 | 23·8525 | 15·6675 | 275·00 | 4308·5625 |
| ·58 | 39·485 | 23·84 | 15·645 | 276·00 | 4318·02 |
| 12·02 | 39·4450 | 23·84 | 15·605 | 277·75 | 4334·28875 |
| ·06 | 39·3425 | 23·85 | 15·4925 | 289·00 | 4477·3325 |
| ·10 | 39·255 | 23·86 | 15·395 | 286·25 | 4406·81875 |
| ·14 | 39·1425 | 23·8825 | 15·26 | 287·00 | 4379·62. |
| ·18 | 39·0775 | 23·8925 | 15·185 | 284·75 | 4323·92875 |
| ·22 | 39·0125 | 23·90 | 15·1125 | 284·00 | 4291·95 |
| ·26 | 38·98 | 23·91 | 15·07 | 289·25 | 4358·9975 |
| ·30 | 38·895 | 23·91 | 14·985 | 287·50 | 4308·1875 |
| ·34 | 38·865 | 23·91 | 14·955 | 290·50 | 4344·4275 |
| ·38 | 38·78 | 23·905 | 14·875 | 293·50 | 4365·8125 |
| ·42 | 38·8175 | 23·915 | 14·9025 | 275·50 | 4105·63875 |
| ·46 | 38·93 | 23·925 | 15·005 | 272·25 | 4085·11125 |
| ·50 | 39·04 | 23·925 | 15·115 | 270·50 | 4088·6075 |
| ·54 | 39·175 | 23·94 | 15·235 | 265·50 | 4044·8925 |
| ·58 | 39·3475 | 23·925 | 15·4225 | 263·50 | 4063·82875 |
| 1·02 | 39·405 | 23·9125 | 15·4925 | 271·00 | 4198·4675 |
| ·06 | 39·45 | 23·9025 | 15·5475 | 273·25 | 4248·354375 |
| 1·10 | 39·4825 | 23·90 | 15·5825 | 272·50 | 4246·23125 |
| ·14 | 39·485 | 23·92 | 15·565 | 273·00 | 4249·245 |
| ·18 | 39·4925 | 23·92 | 15·5725 | 268·00 | 4173·43 |
| ·22 | 39·525 | 23·905 | 15·62 | 267·50 | 4178·35 |
| ·26 | 39·51 | 23·90 | 15·61 | 274·75 | 4288·8475 |
| ·30 | 39·52 | 23·895 | 15·625 | 268·00 | 4187·5 |
| Total number heat units. . . . . . . . . . | | | | | 157735·96550 |

When the experiment was finished, the two cocks on the calorimeter were closed, and the engine stopped. The temperature of the water was then found to be 39°. The time occupied in stopping was about four minutes, equivalent to two minutes on full load. From the data of the previous experiment, the rise of temperature would be about ·85° C. per minute, and therefore the average temperature of the calorimeter during the second experiment was about 37·3°.

From the above table and the dynamometer record, we get the following data:

| | | |
|---|---|---|
| Mean reading scale beam, | | 655·9195 |
| Mean friction reading, | | 13·72 |
| Corrected reading, | | 642·1995 |
| No. revolutions, | | 106,180 |
| Foot pounds absorbed, | | 225585395· |
| Heat units passing through cal. (uncorrected,) | | 157735·96 |
| Heat units radiated from calorimeter, | + | 4045·89 |
| Correction to reduce ther. to abs. temp., | — | 169·63 |
| Stem correction, | + | 647·12 |
| Total heat units, | | 162169·34 |
| Mechanical equivalent for 1° C., | | 1391 05 foot pounds. |
| Mechanical equivalent for 1° F., | | 772·81 foot pounds. |

In this method the uncertainty due to the specific heat of the iron, and its temperature is avoided. The greatest possibilities of error are in the mean temperature of the calorimeter and the stem correction. It is probable that too great a value of the latter has been taken; for the thermometers were in the water for several hours and a considerable portion of the stem must have been heated by conduction.

The coefficient of radiation was taken from the first experiment.

The results of the experiments are:

First method mech. equiv. = 768·3 — an indeterminate correction
Second method mech. equiv. = 772·81

It would seem then that within the limit of error of these experiments, the dynamometer is correct, and, considering the probable accuracy of the last method, there seems little doubt that the work calculated from the dynamometer readings is as accurate as the adjustments of the machine and the readings themselves.

## TESTS.

For the full load tests, the machines were run at least ten hours before any measurements were made. They were then tested at intervals of from one to two hours.

For the partial loads, the dynamos were run on quarter load for two or three hours, then tested, then run on half load for a couple of hours, and tested, etc.

The method of making a test was as follows: A time to begin was set, and the observers got ready to start at the signal from the test house. After the signal, double readings of the potential and current galvanometers were simultaneously made each minute, and the scale beam and number of revolutions of the dynamometer observed. The field galvanometer was reversed, and read as often as possible, usually four or five double readings.

At the end of ten minutes, a signal to stop was made; the dynamo was stopped, the field circuit broken, the storage battery put on, and the armature resistance measured. The brushes were then lifted, and the field circuit made and its resistance measured. Finally, the constants of the current and potential galvanometers were checked on the german silver strips.

When the tests for the day were finished, the friction of the armature and of the dynamometer were obtained, and the latter subtracted from the power applied for each test.

Communication from the test house to the dynamo shed was by an electric bell, and through a speaking tube.

The following notation will be used in the formulae:

$e$ difference of potential between terminals of dynamo;
$E$ total electro-motive force generated in armature;
$i$ current in external circuit;
$i_s$ current in field;
$R$ resistance of external circuit;
$r_a$ resistance of armature coils;
$r_s$ resistance of field with box for adjustment;
$S$ resistance of field alone;
$W$ energy applied in horse-power;
$W_t$ total electrical energy in horse-power;
$W_e$ energy in external circuit in horse-power;
$W_a$ energy in armature in horse-power;

$W_s$ energy in field in horse-power;
$Ef_t$ total efficiency of electrical conversion;
$Ef_c$ useful commercial efficiency;
$\eta$ $= Ef_c / Ef_t$;
$p_a$ percentage of power used in armature;
$p_s$ percentage of power used in field;
$n$ number of revolutions per minute;
*Fric.* friction of armature;
$t_a$ temperature of the air in degrees centigrade;
$t_p$ temperature of pole-piece in degrees centigrade;

Of these, $e$, $i$, $i_s$, $r_a$, $S$, $W$, $n$, $t_a$ and $t_p$ were observed directly.

$E$ was calculated from $E = e + (i + i_s) r_a$;

$R$ was obtained from $R = e / i$;

$r_s$ was from $r_s = e / i_s$; it was also checked by observation after each test.

The other formulæ used were

$$W_t = \frac{(i + i_s) e + (i + i_s)^2 r_a}{745 \cdot 3}$$

$$W_e = \frac{i\, e}{745 \cdot 3}$$

$$W_a = \frac{(i + i_s)^2 r_a}{745 \cdot 3}$$

$$W_s = \frac{i_s\, e}{745 \cdot 3}$$

$$Ef_t = \frac{W_t}{W}$$

$$Ef_c = \frac{W_e}{W}$$

$$\eta = \frac{Ef_c}{Ef_t}$$

$$p_a = \frac{W_a}{W}$$

$$p_s = \frac{W_s}{W}$$

EDISON NO. 5 DYNAMO.

| | |
|---|---|
| Diameter of armature, | $7\frac{1}{16}''$ inner; $7\frac{7}{8}''$ outer. |
| Weight of machine, | 2475 pounds. |
| Number of commutator bars, | 50 |
| Turns of wire in a coil. | 2 |
| Length of useful wire in a coil, | 52″ |
| Brushes adjusted or not? | yes. |
| Diameter of bearing, | $1\frac{5}{16}''$ |
| Length of bearing, | $5\frac{5}{8}''$ |
| Revolutions per minute, | 1400 |
| Volts for best work, | 125 |
| Ampères for best work, | 100 |

Table 1 gives the result of the measurements:

TABLE I.—(*Edison No. 5 Dynamo.*)

| DATE. | May 29th. | | |
|---|---|---|---|
| Time, | 12·40 | 1·40 | 3·00 |
| Load, | Full. | Full. | |
| E. M. F. at terminals, . | 125·2 | 121·59 | |
| Total E. M. F., . . . . | 131·5 | 128·00 | |
| Current in ext. circ , . . | 100·92 | 98·06 | |
| Current in field, . . . . | 2·385 | 2·296 | |
| External resistance, . . | $1\cdot241_{d}$ | $1\cdot240_{d}$ | |
| Armature resistance, . . | ·0613 | ·0638 | Insulation of armature gave way. |
| Field, with box, . . . . | 52·59 | 53·08 | |
| Field, alone, . . . . . | . . . | . . . | |
| Power applied, . . . . | 18·89 | 18·05 | |
| Total elect. energy, . . | 18·23 | 17·24 | |
| Ext. elect energy, . . . | 16·95 | 16·00 | |
| Energy in arm., . . . . | ·878 | ·863 | |
| Energy in field, . . . . | ·401 | ·374 | |
| Total efficiency, . . . . | 96·53 | 95·49 | |
| Commercial efficiency, . | 89·76 | 88·63 | |
| Economic coefficient, . . | 92·99 | 92·82 | |
| % power in arm., . . . | 4·65 | 4·78 | |
| % power in field, . . . | 2·12 | 2·08 | |
| No revolutions, . . . . | 1400·8 | 1389·7 | |
| Friction of arm., . . . . | . . . | . . . | |
| Temp. of air, . . . . . | 26·4° C. | 27·° C. | |
| Temp. of pole-piece, . . | 44·° C. | 45·4° C. | |

This was the first machine tested and the measurements were intended as much to show any weak points in the method as to serve as a test of the dynamo. If no trouble occurred, the work was to be accepted, otherwise it would have been repeated after the causes of error had been removed.

On looking at the table, it will be seen that the efficiencies for the two tests differ by about one per cent. The agreement of the measurements of the current and potentials as shown in the values of the resistances, calculated from them, is very good. Whether the difference is due to the power measurements, or to different conditions of lubrication, velocity, etc., is impossible to say.

After the second test, the insulation of the armature gave way; making it impossible to repeat the full load measurements, or to test on the partial loads.

EDISON NO. 10 DYNAMO.

| | |
|---|---|
| Diameter of armature, | $9\frac{11}{16}''$ inside; $10\frac{5}{8}''$ outside. |
| Weight of machine, | 4710 pounds. |
| Number of commutator bars, | 64 |
| Turns of wire in a coil, | 1 |
| Length of useful wire in a coil, | 33″ |
| Must brushes be adjusted? | yes. |
| Diameter of bearing, | 2⅜″ |
| Length of bearing, | 9⅝″ |
| Number turns per minute, | 1200 |
| Volts for best work, | 125 |
| Ampères for best work, | 200 |

Table II gives the results of the measurements:

There is little to say of the full load measurements of this machine. The extreme difference is about one-half per cent.; the greatest difference from the mean one-fourth per cent.

The dynamo was measured twice on the partial loads. The first set was on the same day as the full load tests, the machine being run on open circuit for a couple of hours after the last full load measurement, then tested for quarter load, then run on half load for a while and tested, etc. The second set, made some days later, showed that the machine had not been sufficiently cooled for the first set of measurements. The total efficiencies, calculated from the two sets of measurements, differ for the quarter load about one and one-half per cent.; for the half load, three-quarter per cent., and for the three-quarter load, one-seventh per cent.

In comparing these total efficiencies, if the difference of armature friction (·152 horse-power) be applied to the first set, we get

| | ¼ load. | ½ load. | ¾ load. |
|---|---|---|---|
| First set, | 83·10 | 90·51 | 92·83 |
| Second set, | 83·32 | 90·55 | 92·44 |

But as the measurement of friction was made after the three-quarter load in each case, the values for this load should agree better than for the others. Part of the difference of ·39 per cent. is undoubtedly due to the fact that in the last set of measurements the unsteadiness of the potential galvanometer while measuring the armature resistance, due to changes in the contact resistance of the brushes, was so great that the brushes were held against the commutator, thus giving too small a value of $r_a$, and therefore of $Ef_t$. On the whole, the agreement of the two sets is very satisfactory.

TABLE II.—(*Edison No. 10 Dynamo.*)

| DATE. | June 1st. | | | | June 1st. | | | June 4th | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Time, | 12·33 | 2·00 | 3·15 | 4·15 | 6·56 | 7·45 | 8·30 | 11·15 | 2·35 | 4·00 |
| Load, | Full. | Full. | Full. | Full. | ¼ | ½ | ¾ | ¼ | ½ | ¾ |
| E.M.F at terminals, | 125·08 | 122·67 | 121·58 | 122·87 | 125·41 | 126·09 | 122·89 | 127·81 | 128·83 | 125·6 |
| Total E.M.F., . . . | 129·35 | 127·18 | 126·05 | 127·27 | 126·81 | 128·74 | 126·85 | 128·73 | 130·67 | 128·33 |
| Current in ext. circ., | 201 48 | 196·51 | 194·56 | 196·48 | 52·07 | 107·05 | 150·60 | 51·81 | 103·79 | 149·92 |
| Current in field, . . | 4·021 | 3·900 | 3·84 | 3·93 | 3·46 | 3·69 | 3·74 | 3·47 | 3·81 | 3·81 |
| External resistance,* | ·6208$_e$ | ·6243$_e$ | ·6249$_e$ | ·6254$_e$ | 2·408$_d$ | 1·177$_d$ | ·8160$_d$ | 2·467$_d$ | 1·213$_d$ | ·8378 |
| Armature resistance, | ·0208 | ·0225 | ·0231 | ·0220 | ·0253 | ·0239 | ·0256 | ·0167 | ·0171 | ·0178 |
| Field, with box, . . | 31·10 | 31·46 | 31·63 | 31·27 | 36·24 | 34·14 | 32·83 | 36·82 | 33·83 | 33·01 |
| Field, alone, . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . |
| Power applied, . . | 37·69 | 35·98 | 35 53 | 36·19 | 11 556 | 21·30 | 28·46 | 11·459 | 20·83 | 28·64 |
| Total elec. energy, . | 35 67 | 34·20 | 33·58 | 34·22 | 9·449 | 19·13 | 26·27 | 9·548 | 18·86 | 26·47 |
| Ext. elec. energy, . | 33·81 | 32·34 | 31·74 | 32·66 | 8·762 | 18·11 | 24·83 | 8·884 | 17·94 | 25·27 |
| Energy in arm., . | 1·178 | 1·212 | 1·218 | 1·182 | ·105 | ·393 | ·820 | ·0686 | ·265 | ·564 |
| Energy in field, . . | ·675 | ·642 | ·627 | ·648 | ·582 | ·625 | ·617 | ·595 | ·658 | ·641 |
| Total efficiency, . . | 94 61 | 95 04 | 94·52 | 94·56 | 81·77 | 89·80 | 92·30 | 83·32 | 90·55 | 92·44 |
| Commerc'l efficiency. | 89 70 | 89·89 | 89·34 | 89·52 | 75·82 | 85·02 | 87·25 | 77·53 | 86·12 | 88·23 |
| Economic coefficient, | 94 80 | 94·58 | 94·51 | 94·65 | 92·73 | 94·68 | 94·53 | 93·05 | 95·10 | 95·45 |
| % power in arm., . | 3·12 | 3·36 | 3·43 | 3·26 | ·906 | 1·85 | 2·88 | ·598 | 1·28 | 1·97 |
| % power in field, . | 1·80 | 1·79 | 1·76 | 1·78 | 5·04 | 2·93 | 2·16 | 5·20 | 3·16 | 2·24 |
| No. revolutions, . . | 1208 6 | 1197·6 | 1193·3 | 1199·3 | 1207·6 | 1207·7 | 1202·6 | 1211·7 | 1211·1 | 1209·3 |
| Friction of arm., . . | ·437 | ·437 | ·437 | ·437 | ·437 | ·437 | ·437 | ·285 | ·285 | ·285 |
| Temp. of air, . . . | 30·5° C. | 30·5° C. | 30.5° C. | 28·0 C. | 26·5° C. | 27·5° C. | 27·0° C. | 25·5° C. | 28·5° C. | 31·0° C. |
| Temp. of polep·iece, | 50·5° C. | 50·5° C. | 51·5° C. | 56·5° C. | 35·5° C. | 44·5° C. | 44·0° C. | 38·0° C. | 45·6° C. | 46·7° C. |

* The suffix e refers to lamps and d to "dead" resistance.

WESTON NO. 7 M. DYNAMO.

| | |
|---|---|
| Diameter of armature, | 9⅜″ |
| Weight of machine, | 3300 |
| Number of commutator bars, | 64 |
| Total number of turns in coils, | 128 |
| Turns per commutator segment, | 2 |
| Average length of a turn, | 6 feet, 8″ |
| Must brushes be adjusted? | slightly. |
| Diameter of bearing, pulley end, | 2″ |
| Diameter of bearing, commutator end, | 1½″ |
| Length of bearing, pulley end, | 7½″ |
| Length of bearing, commutator end, | 6½″ |
| Number of turns per minute, | 1050 |
| Volts for best work, | 160 |
| Ampères for best work, | 125 |

Table III gives the results of the measurements:

As stated under "potential measurements," there was a sharp change in the value of the constant of the potential galvanometer between the second and third tests. The following are the calibrations made:

| Time. | Value of $K_{50}$ | Method. |
|---|---|---|
| A. M. | at 25 degrees. | |
| 10·00 | 1·305 | Voltameter with standard resistance. |
| 11·35 | 1·307 | Current galvanometer with german-silver strips. |
| P. M | | |
| 12·50 | 1·308 | Current galvanometer with german-silver strips. |
| 2·50 | 1·287 | Current galvanometer with german-silver strips. |
| 3·05 | 1·286 | Voltameter with standard resistance. |
| 4·15 | 1 286 | Voltameter with standard resistance. |

For the first two tests, the value 1·306 was used; for the last two, 1·286.

The tables show a gradual decrease in the efficiencies, the difference between the first and last values being about one per cent

The cause seems to be the different amounts of lead given the brushes. If we compare the first with the third test, it will be seen that, with about the same current in the field and a greater

TABLE III.—(*Weston No. 7 M. Dynamo.*)

| DATE | June 8th. | | | | June 12th. | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Time, | 11·15 | 12.26 | 2.27 | 3·45 | 12·00 | 2·00 | 3·45 | 4·30 | 6·00 |
| Load, | Full. | Full. | Full. | Full. | ¼ | ½ | ¾ | Full. * | ½ |
| E. M. F. at terminals, . | 156·07 | 154·84 | 151·42 | 151·22 | 163·66 | 163·41 | 163·93 | 166·48 | 167·60 |
| Total E. M. F., . . . | 165·58 | 163·99 | 160·79 | 160·31 | 166·07 | 168·29 | 172·65 | 176·30 | 172·77 |
| Current in. ext. circ., . | 125·78 | 124·86 | 123·13 | 123·57 | 33·26 | 66·27 | 99.25 | 133·82 | 67·68 |
| Current in field, . . . | 2·378 | 2·340 | 2·341 | 2·332 | 1·738 | 1·872 | 2·163 | 2·439 | 1·959 |
| External resistance, . . | $1·241_d$ | $1·240_d$ | $1·230_e$ | $1·224_e$ | $4·921_d$ | $2·466_d$ | $1·652_d$ | $1·244_d$ | $2·476_d$ |
| Armature resistance, . | ·0742 | ·0720 | ·0747 | ·0722 | ·0689 | ·0716 | ·0683 | ·0720 | ·0742 |
| Field, with box, . . . | 65·62 | 66·18 | 64·70 | 64·86 | 94·16 | 87·31 | 75·78 | 68·25 | 85·54 |
| Field, alone, . . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . |
| Power applied, . . . | 29·29 | 29·01 | 28·07 | 28·17 | 8·658 | 16·223 | 24·123 | 33·257 | 17·08 |
| Total elec. energy, . . | 28·47 | 27·98 | 27·07 | 27·08 | 7·798 | 15·387 | 23·25 | 32·23 | 16·144 |
| Ext. elec. energy, . . | 26·34 | 25·94 | 25·02 | 25·07 | 7·304 | 14·53 | 21·83 | 29·89 | 15·22 |
| Energy in arm., . . . | 1·635 | 1·562 | 1·578 | 1·536 | ·1131 | ·446 | ·943 | 1·796 | ·483 |
| Energy in field, . . . | ·498 | ·486 | ·476 | ·473 | ·382 | ·410 | ·476 | ·545 | ·441 |
| Total efficiency, . . . | 97·21 | 96·48 | 96·45 | 96·12 | 90·08 | 94·84 | 96·38 | 96·92 | 94·52 |
| Commercial efficiency, . | 89·92 | 89·42 | 89·14 | 89·00 | 84·37 | 89·57 | 90·49 | 89·87 | 89·12 |
| Economic coefficient, . | 92·51 | 92·68 | 92·41 | 92·58 | 93·65 | 94·41 | 93·90 | 92·73 | 94·28 |
| % power in arm., . . | 5·59 | 5·39 | 5·63 | 5·45 | 1·31 | 2·75 | 3·91 | 5·40 | 2·82 |
| % power in field, . . . | 1·70 | 1·68 | 1·69 | 1·68 | 4·41 | 2·53 | 1·98 | 1·63 | 2·58 |
| No. revolutions, . . . | 1043·5 | 1039 0 | 1045·6 | 1051·7 | 1041·4 | 1038·8 | 1024·1 | 1058·8 | 1051·3 |
| Friction of arm., . . . | ·3115 | ·3115 | ·3115 | ·3115 | ·1956 | ·1956 | ·1956 | ·1956 | ·1956 |
| Temp. of air, . . . . | 30·° C. | 30·5° C. | 30·° C. | 30·° C. | 29.5° C. | 31·° C. | 30·5° C. | 29·° C. | 28·° C. |
| Temp. of pole-piece,. . | 42·° C. | 42·2° C. | 42·8° C. | 47·8° C. | 33·3° C. | 35·° C. | 36·5° C. | 36·° C. | 35·5° C. |

* Unofficial.

number of revolutions of the armature, the *E. M. F.* of the latter test is about five volts less than that of the former. In the last test, with the speed still further increased and with the field current about constant, the *E. M. F.* is slightly less than in the third measurement.

The partial load tests were made after the constant had become steady. After the three-quarter load test, a measurement was made on full load. As it was not made under the provisions of the code, it is marked "unofficial" in the table. The half load test was repeated to check the former measurement. The difference of ·3 per cent in the total efficiencies is probably accounted for by the slight increase of armature friction caused by running on the three-quarter load. The greatest value of the commercial efficiency is on three-quarter load, the slightly less value of the total efficiency, as compared with the full load, being more than counter-balanced by the smaller loss in the armature and field.

WESTON NO. 6 M. DYNAMO.

| | |
|---|---|
| Diameter of armature, | $8\frac{1}{32}''$ |
| Weight of machine, | 2000 |
| Number of commutator bars, | 72 |
| Total number of turns, | 144 |
| Turns per commutator segment, | 2 |
| Average length of a turn, | 6 feet 5″ |
| Must brushes be adjusted? | slightly. |
| Diameter of bearing, pulley end, | $1\frac{5}{8}''$ |
| Diameter of bearing, commutator end, | $1\frac{3}{8}''$ |
| Length of bearing, pulley end, | $6\frac{3}{4}''$ |
| Length of bearing, commutator end, | 5″ |
| Number of turns per minute, | 1150 |
| Volts for best work, | 120 |
| Ampères for best work, | 80 |

Table IV gives the results of the measurements:

The full load measurements probably agree as closely as the conditions of the tests. There was a good deal of sparking at the brushes, and the machine seemed overloaded.

For the partial loads, the total efficiency increased up to the three-quarter load, and there was little sparking at the commutator. On the unofficial full load test, the sparking was quite violent, and the efficiency fell about two per cent. from the three-quarter load. Com-

TABLE IV.—(*Weston No. 6 M. Dynamo.*)

| DATE | June 13th. | | | | June 14th. | | | |
|---|---|---|---|---|---|---|---|---|
| Time, | 11·52 | 1·50 | 2·25 | 3·55 | 12·15 | 2·20 | 4·00 | 4·39 |
| Load, | Full. | Full. | Full. | Full. | ¼ | ½ | ¾ | Full.* |
| E.M.F. at terminals, | 117·4 | 115·4 | 118·89 | 119·86 | 119·70 | 122·41 | 119·19 | 124·41 |
| Total E. M. F., . | 124·59 | 122·37 | 126·26 | 127·17 | 121·70 | 126 28 | 125·12 | 131·76 |
| Current in ext. circ. | 71·85 | 70·62 | 72·45 | 71·56 | 20·535 | 39·878 | 60·705 | 75·65 |
| Current in field, . | 1·277 | 1·254 | 1·280 | 1·286 | 1·236 | 1·214 | 1·246 | 1·318 |
| External resistance, | 1·634$_d$ | 1·634$_d$ | 1·641$_d$ | 1·675$_e$ | 5·827$_e$ | 3·070$_e$ | 1·963$_d$ | 1·645$_d$ |
| Armature resistance | ·0983 | ·0969 | ·0999 | ·1003 | ·0921 | ·0940 | ·0957 | ·0956 |
| Field with box, . | 91·93 | 92·00 | 92·91 | 93·20 | 96·79 | 100·9 | 95·69 | 94·42 |
| Field alone, . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . |
| Power applied, . . | 12·89 | 12·48 | 13·15 | 13·17 | 3·979 | 7·341 | 10·774 | 14·390 |
| Total elec. energy, | 12·23 | 11·80 | 12·49 | 12·429 | 3·554 | 6·962 | 10·40 | 13·606 |
| Ext. elect. energy, | 11·32 | 10 93 | 11·56 | 11·508 | 3·297 | 6·55 | 9·708 | 12·627 |
| Energy in arm., . | ·705 | ·672 | ·729 | ·714 | .0585 | ·213 | ·493 | ·759 |
| Energy in field, . | ·201 | ·194 | ·204 | ·207 | ·1985 | ·1993 | ·1992 | ·2199 |
| Total efficiency, . | 94·82 | 94·53 | 94·98 | 94·37 | 89·33 | 94·84 | 96·53 | 94·55 |
| Commer'l efficiency | 87·79 | 87·59 | 87·88 | 87·38 | 82·87 | 89·23 | 90·10 | 87·75 |
| Econo'ic coefficient, | 92·58 | 92·66 | 92·53 | 92·59 | 92·77 | 94·08 | 93·34 | 92·80 |
| % power in arm., . | 5·48 | 5·38 | 5·56 | 5·43 | 1·47 | 2·90 | 4·58 | 5·28 |
| % power in field, . | 1·56 | 1·56 | 1·56 | 1·57 | 4·99 | 2·71 | 1·85 | 1·53 |
| No. revolutions, . | 1099·6 | 1101·9 | 1117·8 | 1114·9 | 1110·7 | 1109·5 | 1113·7 | 1154·2 |
| Friction of arm., . | ·298 | ·298 | ·298 | ·298 | ·1672 | ·1672 | ·1672 | .1672 |
| Temp. of air, . . | 30·4° C. | 31·° C. | 30·5° C. | 30·5° C. | 34·° C. | 33·5° C. | . . . | . . . |
| Temp. of pole-piece | 37·7° C. | 41·2° C. | 41·6° C. | 41·5° C. | 36·7 C. | 39·5° C. | . . . | . . . |

* Unofficial.

paring the unofficial full load with the tests of the day before, and applying the difference of armature friction to the former, it will be seen that the total efficiency for the unofficial test is less, the load being greater and the efficiency at this load decreasing rapidly as the load increases.

EDISON NO. 4 DYNAMO.

| | |
|---|---|
| Diameter of armature, $6\frac{1}{4}''$ inside, $7\frac{1}{16}''$ outside | |
| Weight of machine, | 1470 |
| Number of commutator bars, | 50 |
| Turns in one coil, | 2 |
| Length of useful wire in a coil, | 48″ |
| Must brushes be adjusted? | yes. |
| Diameter of bearing, | $1\frac{1}{2}''$ |
| Length of bearing, | $6\frac{1}{4}''$ |
| Turns per minute, | 1600 |
| Volts for best work, | 125 |
| Ampères for best work, | 80 |

Table V gives the results of the measurements:

This machine was not coupled directly to the dynamometer, the high speed required being deemed unsafe. It was run by a belt from a pulley on the transmission shaft of the dynamometer. In allowing for the loss due to the belt, it was assumed that for the full load the friction of the armature was the same as that of the No. 5 dynamo.

The full load tests agree very closely, the total efficiencies increasing slightly with the horse-power. The commercial efficiencies differing very little.

The measurements on the partial loads are perhaps a little low, as it is probable that sufficient allowance was not made for the belt. The temperature was much lower than for the full load tests and the belt was probably stiffer.

## Table V.—(*Edison No. 4 Dynamo.*)

| Date. | June 16th. | | | | June 17th. | | | |
|---|---|---|---|---|---|---|---|---|
| Time, | 2·16 | 3.30 | 4·25 | 5·20 | 11·00 | 12·15 | 2·15 | 2·40 |
| Load, | Full. | Full. | Full. | Full. | ¼ | ½ | ¾ | Full.* |
| E. M. F. at terminals, | 120·05 | 124·95 | 125·20 | 126·75 | 128·66 | 128·77 | 128·39 | 131·17 |
| Total E. M. F., . . | 124·64 | 129·61 | 129·97 | 131·91 | 130·00 | 131.09 | 132·22 | 137·08 |
| Current in ext. circ., | 72·919 | 75·93 | 76·12 | 82·10 | 22·36 | 39·55 | 63·58 | 90·68 |
| Current in field, . . | 1·915 | 2·244 | 2·211 | 2·321 | 1·940 | 2·082 | 2·222 | 2·647 |
| External resistance, . | 1·646$_d$ | 1·646$_d$ | 1·647$_d$ | 1·543$_e$ | 5·755$_e$ | 3·256$_d$ | 2·019$_e$ | 1·446$_e$ |
| Armature resistance, | ·c614 | ·0596 | ·0610 | ·0611 | ·0550 | ·0556 | ·0582 | ·0634 |
| Field, with box, . . | 62 68 | 55·68 | 56·63 | 54·58 | 66·33 | 61·85 | 57·78 | 49·55 |
| Field, alone, . . . | 44·17 | 44·46 | 44·69 | 44·59 | 40·42 | 41·21 | 42·29 | . . . |
| Power applied, . . | 13·284 | 14·383 | 14·442 | 15·786 | 5·050 | 8·168 | 12·517 | 18·053 |
| Total elect. energy, . | 12·51 | 13·60 | 13·64 | 14·93 | 4·237 | 7·322 | 11·67 | 17·17 |
| Ext. elec. energy, . | 11·746 | 12·73 | 12·77 | 13·95 | 3·859 | 6·833 | 10·95 | 15·96 |
| Energy in arm., . . | ·461 | ·488 | ·501 | ·584 | ·0436 | ·129 | ·338 | ·741 |
| Energy in field, . . | ·309 | ·376 | ·371 | ·394 | ·335 | ·360 | ·382 | ·466 |
| Total efficiency, . . | 94·21 | 94·53 | 94·47 | 94·58 | 83·89 | 89 65 | 93·26 | 95·09 |
| Commercial efficiency | 88·42 | 88·52 | 88·43 | 88·38 | 76·40 | 83·65 | 87·50 | 88·40 |
| Economic coefficient, | 93·85 | 93·64 | 93·61 | 93·45 | 91·07 | 93·32 | 93·82 | 92·97 |
| % of power in arm., . | 3·47 | 3·40 | 3·47 | 3·70 | ·86 | 1·59 | 2·70 | 4·10 |
| % of power in field, . | 2·32 | 2·61 | 2·57 | 2·49 | 6·63 | 4·41 | 3·06 | 2·58 |
| No. revolutions, . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . |
| Friction of arm., . . | ·14 | ·14 | ·14 | ·14 | ·16 | ·16 | ·16 | ·16 |
| Temp. of air, . . . | 35·5° C. | 36·5° C. | 36·2° C. | 36·° C. | 21·° C. | 23·° C. | 25·° C. | 24·8° C. |
| Temp. of pole-end, . | 45·8° C. | 45·5° C. | 46·1° C. | 45·5° C. | 27·2° C. | 29·5° C. | 33·3° C. | 34·6° C. |

* Unofficial.

EDISON NO. 20 DYNAMO.

| | |
|---|---|
| Diameter of armature, | $9\frac{1}{16}$ inside, $10\frac{5}{8}$ outside. |
| Weight of machine, | 8331 pounds. |
| Number of commutator bars, | 44 |
| Turns of wire in a coil, | 1 |
| Length of useful wire in a coil, | 59″ |
| Must brushes be adjusted ? | yes. |
| Diameter of bearing, | $2\frac{5}{8}$″ |
| Length of bearing, | $10\frac{7}{8}$″ |
| Number of turns per minute, | 1000 |
| Volts for best work, | 125 |
| Ampères for best work, | 400 |

Table VI gives the results of the measurements :

The full load tests are marked unofficial, because the preliminary run of ten hours was not on full load. The machine was started at the usual time, midnight, with about the right load, but in a few hours the power fell to about fifty horse-power, and remained about the same until noon of June 19th, when by increasing the number of revolutions, the proper load was nearly attained. The tests were to have been repeated the next day, but unfortunately the insulation of the armature gave way, making this impossible.

The tests seem to agree quite well. It is hard to compare the first full load measurement with the others as the conditions were different. The two full load measurements made under about the same conditions agree almost exactly.

TABLE VI.—(*Edison No. 20 Dynamo.*)

| Date. | June 18th. | | | June 19th. | | | |
|---|---|---|---|---|---|---|---|
| Time, | 1·00 | 2·25 | 3·50 | 9·45 | 1·30 | 2·45 | 4·00 |
| Load, | ¼ | ½ | ¾ | Full.* | Full.* | Full.* | |
| E. M. F. at terminals, | 126·16 | 122·0 | 123·99 | 105·95 | 125·04 | 125·4 | |
| Total E. M. F., . . . | 127·46 | 124·10 | 127·55 | 110·00 | 129·60 | 129·95 | |
| Current in ext. circ., | 100·22 | 192·46 | 291·16 | 330·88 | 387·28 | 379·00 | |
| Current in field, . . | 4·942 | 4·915 | 5·124 | 4·397 | 5·136 | 5·124 | |
| External resistance, . | 1·258$_a$ | ·6338$_a$ | ·4161$_a$ | ·3202$_a$ | ·3229$_a$ | ·3308$_a$ | |
| Armature resistance, | ·0124 | ·0106 | ·0120 | ·0121 | ·0116 | ·0119 | Armature insulation gave way. |
| Field, with box, . . | 25·53 | 24·82 | 24·20 | 24·10 | 24·35 | 24·47 | |
| Field, alone. . . . | . . . | . . . | . . . | . . . | . . . | . . . | |
| Power applied, . . | 20·254 | 35·43 | 53·11 | 51·06 | 70·72 | 69·39 | |
| Total elec. energy, . | 17·985 | 32·86 | 50·71 | 49·48 | 68·25 | 66·97 | |
| Ext. elec. energy, . | 16·965 | 31·50 | 48·44 | 47·04 | 64·99 | 63·76 | |
| Energy in arm., . . | ·1838 | ·556 | 1·416 | 1·82 | 2·40 | 2·35 | |
| Energy in field, . . | ·837 | ·809 | ·852 | ·625 | ·862 | ·862 | |
| Total efficiency, . . | 88·80 | 92·77 | 95·46 | 96·91 | 96·51 | 96·52 | |
| Commercial efficiency | 83·76 | 88·93 | 91·19 | 92·11 | 91·90 | 91·89 | |
| Economic coefficient, | 94·33 | 95·86 | 95·53 | 95·06 | 95·22 | 95·21 | |
| % power in arm., . | ·91 | 1·57 | 2·66 | 3·57 | 3·39 | 3·38 | |
| % power in field, . . | 4·13 | 2·27 | 1·61 | 1·23 | 1·22 | 1·25 | |
| No. revolutions, . . | 1008·9 | 1023·9 | 1008·8 | 1022·3 | 1092·1 | 1090·2 | |
| Friction of arm., . . | . . . | . . . | . . . | ·393 | ·393 | ·393 | |
| Temp. of air. . . . | 28·5° C. | 28·5° C. | 28·5° C. | 31·5° C. | 33·° C. | 33·5° C. | |
| Temp. of pole-piece, | 35·0° C. | 37·8° C. | 38·3° C. | 44·5° C. | 45·° C. | 47·8° C. | |

WESTON NO. 6 W. I. DYNAMO.

| | |
|---|---|
| Diameter of armature, | 8¼″ |
| Weight of machine, | 2100 pounds |
| Number of commutator bars, | 56 |
| Total number of turns in armature coils, | 112 |
| Turns per commutator segment, | 2 |
| Average length, | 6 feet, 3½″ |
| Must brushes be adjusted? | slightly |
| Diameter of bearing, pulley end, | 1⅝″ |
| Diameter of bearing, commutator end, | 1⅜″ |
| Length of bearing, pulley end, | 6¾″ |
| Length of bearing, commutator end, | 5″ |
| Turns per minute, | 1200 |
| Volts for best work, | 130 |
| Ampères for best work, | 100 |

Table VII gives the results of the measurements:

The values of the total efficiency for the different measurements of this machine differ widely. The first test gives a much smaller value than the rest, and is rejected, because, whether the difference is caused by errors in the measurements, or in the adjustment of the machine, the test evidently does not represent the normal efficiency of the dynamo.

TABLE VII.—(*Weston No. 6 W. I. Dynamo, 130 Volts*).

| Date | June 22d. | | June 23d. | | | | |
|---|---|---|---|---|---|---|---|
| Time, | . . . | 2·00 | 12·40 | 2·20 | 3·35 | 4·35 | 5·35 |
| Load, | ¼ | ½ | Full.* | Full. | Full. | Full. | ¾ |
| E. M. F. at terminals, | 125·06 | 124·29 | 128·45 | 129·00 | 124·8 | 131·8 | 133·7 |
| Total E. M. F., . . | 126·17 | 126·34 | 133·12 | 133·87 | 129·89 | 136·22 | 137·19 |
| Current in ext. circ., | 25·51 | 46·19 | 108·94 | 109·29 | 114·2 | 98·33 | 81·99 |
| Current in field., . . | 2·051 | 2·144 | 2·239 | 2·213 | 2·171 | 2·272 | 2·242 |
| External resistance, . | $4·901_d$ | $2·691_d$ | $1·180_d$ | $1·180_d$ | $1·093_e$ | $1·340_e$ | $1·630_e$ |
| Armature resistance, | ·0404 | ·0424 | ·0420 | ·0437 | ·0438 | ·0439 | ·0441 |
| Field, with box, . . | 60·96 | 57·96 | 57·37 | 58·28 | 57·51 | 58·01 | 59·62 |
| Field, alone, . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . |
| Power applied, . . | 5·092 | 8·820 | 20·98 | 20·71 | 21·01 | 19·28 | 16·48 |
| Total elec. energy, . | 4·666 | 8·193 | 19·86 | 20·03 | 20·29 | 18·39 | 15·50 |
| Ext. elect. energy, . | 4·281 | 7·703 | 18·78 | 18·92 | 19·13 | 17·39 | 14·70 |
| Energy in arm., . | ·0412 | ·1329 | ·697 | ·729 | ·795 | ·596 | ·394 |
| Energy in field, . . | ·344 | ·358 | ·386 | ·383 | ·364 | ·402 | ·402 |
| Total efficiency, . | 91·64 | 92·89 | 94·68 | 96·69 | 96·53 | 95·39 | 94·06 |
| Commercial efficiency | 84·07 | 87·32 | 89·51 | 91·32 | 91·02 | 90·21 | 89·22 |
| Economic coefficient, | 91·74 | 94·01 | 94·54 | 94·45 | 94·29 | 94·57 | 94·86 |
| % power in arm., . | ·81 | 1·51 | 3·32 | 3·52 | 3·78 | 3·09 | 2·39 |
| % power in field, . . | 6·76 | 4·05 | 1·84 | 1·85 | 1·73 | 2·09 | 2·44 |
| No. revolutions, . . | 1167·2 | 1168·3 | 1258·5 | 1267·6 | 1250·6 | 1257·6 | 1252·3 |
| Friction of arm., . . | . . . | . . . | . . . | ·13 | ·13 | ·13 | ·13 |
| Temp. of air, . . . | 31·° C. | 31·° C. | 27·5° C. | 27·5° C. | 25·° C. | 25·7° C. | . . . |
| Temp. of pole-piece, | 35·° C. | 37·° C. | 35·5° C. | 35·5° C. | 36·7° C. | 36·7° C. | . . . |

* Rejected.

Table VIII gives a summary of the tests:

TABLE VIII.—(*Table of Efficiencies.*)

| | Volts. | Ampères. | Weight. | Total Efficiencies. | | | | Commercial Efficiencies. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Full Load.‡ | ¾ Load. | ½ Load. | ¼ Load. | Full Load.‡ | ¾ Load. | ½ Load. | ¼ Load. |
| Edison, No. 4, . . | 125 | 80 | 1,470 lbs. | 94·45 | 93·26 | 89·65 | 83·89 | 88·44 | 87·40 | 83·65 | 76·40 |
| Edison No. 5,* . . | 125 | 100 | 2,475 lbs. | 96·01 | . . | . . | . . | 89·19 | . . | . . | . . |
| Edison No. 10, . . | 125 | 200 | 4,710 lbs. | 94·68 | 92·44 | 90·55 | 83·32 | 89·61 | 88·23 | 86·12 | 77·53 |
| Edison No. 20,* . . | 125 | 400 | 8,331 lbs. | 96·65† | 95·46 | 92·77 | 88·80 | 91·96† | 91·19 | 88·93 | 83·76 |
| Weston 6 M., . . . | 120 | 80 | 2,000 lbs. | 94·67 | 96·53 | 94·84 | 89·33 | 87·66 | 90·10 | 89·23 | 82·87 |
| Weston 7 M., . . . | 160 | 125 | 3,300 lbs. | 96·56 | 96·38 | 94·84 | 90·08 | 89·37 | 90·49 | 89·57 | 84·37 |
| Weston 6 W. I., . . | 130 | 100 | 2,100 lbs. | 96·20 | 94·06 | 92·89 | 91·64 | 90·85 | 89·22 | 87·32 | 84·07 |

* Armature insulation gave way.
† Unofficial.
‡ Average of full load measurements.

In the table, the full load efficiencies of the Edison No. 20 dynamo are marked "unofficial," because the preliminary run was not in conformity with the code, not because there is any reason to mistrust the results.

Of the fifty-four measurements made, four were for obvious reasons deemed unworthy of calculation. These were two tests of the Edison No. 5 dynamo, and a couple of partial load tests of the Weston No. 7 M machine, made while the constant of the potential galvanometer was unsteady. Of the remaining fifty tests, but one is rejected—a full load measurement of the Weston 6 W. I. dynamo.

Considering the care taken in standardizing all of the instruments used in the measurements, and the very close agreement of tests made on the same dynamo, it seems probable that the results given in the above table represent very nearly the efficiencies of the machines under the conditions of the tests.

The dynamos were favored by being coupled directly to the dynamometer, and it will be seen on looking at the tables that the loss by friction was slight.

In the measurements, the ohm was taken at 106 centimetres of mercury, so in order to reduce the values to absolute measure the potentials, and, therefore, the efficiencies, should be reduced by about one-fourth per cent.

LOUIS DUNCAN, *Chairman.*
GEO. L. ANDERSON, *Secretary.*
WM. D. MARKS,
J. B. MURDOCK,
A. B. WYCKOFF.

FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA

FOR THE

PROMOTION OF THE MECHANIC ARTS.

# MECHANICAL AND ELECTRICAL TESTS

OF

# Conducting Wires.

Report of a Special Committee, appointed by the President of the Franklin Institute in conformity with a Resolution of the Board of Managers, passed November 12, 1884.

[ISSUED BY AUTHORITY OF THE BOARD OF MANAGERS AND PUBLISHED AS A SUPPLEMENT TO THE JOURNAL OF THE FRANKLIN INSTITUTE, NOVEMBER, 1885.]

PHILADELPHIA:
THE FRANKLIN INSTITUTE.
1885.

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FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA.
FOR THE PROMOTION OF THE MECHANIC ARTS.

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## Mechanical and Electrical Tests of Conducting Wires

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*To the Board of Managers of the* Franklin Institute:

Gentlemen:—I herewith transmit the report of the Committee, consisting of Lieut. George L. Anderson, U. S. A., for the electrical tests, and Mr. J. W. Grant, Engineer of Tests (Fairbanks & Co.), for the mechanical tests, appointed under authority of the resolution of the Board, adopted November 12, 1884, to conduct examinations and tests of conducting wires exhibited at the Electrical Exhibition. Very respectfully,

W. P. Tatham, *President.*

Philadelphia, September 3, 1885.

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Mr. William P. Tatham,

*President of the* Franklin Institute, *Philadelphia:*

Sir:—I have the honor to transmit herewith the results of electrical tests made on various kinds of wires, sent for trial to the Philadelphia Electrical Exhibition of 1884. The data contained in the left half of the sheet were copied from the labels found attached to the coils of wire, and in two or three instances it will be seen that the number of the gauge does not agree with the diameter measured. It is thought, therefore, that some of the labels may have been misplaced before the coils reached the Franklin Institute. The figures in the right half of the sheet were those obtained from measurement. The length given in column VI is that portion of the coil of which the resistance was measured, and which is given in column VIII.

I am, very respectfully, your obedient servant,

George L. Anderson, U. S. A.

Newport, R. I., July 19, 1885.

*Electrical Conductivity of Wires sent to International Electrical Exhibition, Philadelphia, 1884.*

| Marks found on Labels tied to the Coils. | | | | | Measurements Taken and Computed. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| I. Gauge Number. | II. Gauge Name. | III. Description. | IV. Metal. | V. Name of Company Sending. | VI. Length of Coil in Feet. | VII. Diameter of Wire in Inches. | VIII. Measured Resistance of Piece or Coil in B. A. Ohms at 75° F. | IX. Resistance of 1,000 feet of Same. | X. Per cent. of Conductivity Referred to Soft, Pure Copper, at 75° F.* | Remarks. |
| 12 | B W G | Bare, hard drawn | Copper, | Bridgeport Brass Co., Bridgeport, Conn., | 1398· | ·109 | 1·289 | ·9221 | 97·3 | |
| 14 | B W G | Bare, hard drawn | Copper, | Bridgeport Brass Co., Bridgeport, Conn., | 2050· | ·083 | 3·259 | 1·590 | 97·3 | |
| 12 | B W G | Bare, hard drawn | Copper, | Holmes, Booth & Haydens, New York, | 131·4 | ·083 | ·212 | 1·612 | 96·0 | |
| 8 | F B B | Bare, telegraph | Iron, | Washburn & Moen Mfg. Co., Worcester, Mass., | 52·8 | ·157 | 1·661 | 31·455 | 13·75 | |
| 8 | F B B | Bare, telegraph | Iron, | Washburn & Moen Mfg. Co., Worcester, Mass., | 52·8 | ·159 | 1·620 | 30·668 | 13·75 | |
| 14 | . . . | Bare, hard drawn | Telegraph copper, | Washburn & Moen Mfg. Co., Worcester, Mass., | 52·8 | ·084 | ·0829 | 1·570 | 96·2 | |
| 14 | . . . | Bare, hard drawn | Telegraph copper, | Washburn & Moen Mfg. Co., Worcester, Mass., | 52·8 | ·084 | ·083 | 1·571 | 96·1 | |
| 14 | B W G | Bare, soft drawn | Telegraph copper, | Washburn & Moen Mfg. Co., Worcester, Mass., | 52·8 | ·083 | ·084 | 1·591 | 97·2 | |
| 12 | . . . | K. K. patent | Ins. Tel. iron | Holmes, Booth & Haydens, New York, | Insul. re | sistance | 100 ft. = | 12 X $10^6$ | ohms. | |
| 16 | B W G | Patent finish painted | Electric light, copper, | Holmes, Booth & Haydens, New York, | Insul. re | sistance | 100 ft. = | 9 X $10^6$ | ohms. | |
| 14 | B W G | Cotton cov. single wound | Copper, | Holmes, Booth & Haydens, New York, | 87·8 | ·083 | ·140 | 1·594 | 97·2 | |
| 14 | B & S G | Cotton cov. single wound | Magnet copper, | Holmes, Booth & Haydens, New York, | 62·3 | ·0641 | ·1663 | 2·669 | 97·2 | |
| 16 | B W G | Patent finish painted | Electric light, copper, | Holmes, Booth & Haydens, New York, | 57·5 | ·0508 | ·2446 | 4·254 | 97·1 | |
| 16 | B & S G | Cotton cov. single wound | Magnet copper, | Holmes, Booth & Haydens, New York, | 55· | ·0508 | ·2337 | 4·25 | 97·2 | |
| 14 | B & S G | Cotton cov. single wound | Magnet copper, | Holmes, Booth & Haydens, New York, | 44·5 | ·0641 | ·1186 | 2·666 | 97·3 | |
| 13 | B & S G | Cotton cov. double wound | Magnet copper, | Holmes, Booth & Haydens, New York, | 72·5 | ·072 | ·153 | 2·112 | 97·4 | |
| 14 | B & S G | Cotton cov. single wound | Magnet copper, | Holmes, Booth & Haydens, New York, | 48·0 | ·083 | ·0763 | 1·59 | 97·3 | |
| 10 | B & S G | Cotton cov. single wound | Magnet copper, | Holmes, Booth & Haydens, New York, | 35· | ·134 | ·0214 | ·6101 | 97·3 | |
| 6 | B & S G | Cotton cov. single wound | Magnet copper, | Holmes, Booth & Haydens, New York, | 52·8 | ·162 | ·022 | ·4175 | 97·3 | |
| 6 | B & S G | Cotton cov. double wound | Magnet copper, | Holmes, Booth & Haydens, New York, | 48·3 | ·162 | ·02016 | ·4175 | 97·3 | |
| 12 | B W G | Magnet covered. | Copper, | Holmes, Booth & Haydens, New York, | 43·0 | ·134 | ·0267 | ·6095 | 97·4 | |

* The resistance of one mill-foot of soft pure copper wire is taken as 10·66 B. A. ohms, at 75° Fahr

PHILADELPHIA, August 31, 1885.

MR. WM P. TATHAM, *President of the* FRANKLIN INSTITUTE.

SIR :---I transmit the following results of mechanical tests of wire submitted.

| Gauge No. | Description. | Company Sending | Diameter in. | Broke at in Pounds. | Average. | Elongation. Per Cent. in 12 inches. | Average. |
|---|---|---|---|---|---|---|---|
| No. 12, B W G | Hard drawn copper wire, | Bridgeport Brass Co., Conn., | ·108 | 680 | . . | 1·2 | . . |
| | Hard drawn copper wire, | Bridgeport Brass Co., Conn., | ·108 | 675 | 677·5 | 1·3 | 1·25 |
| No. 14 B W G | Hard drawn copper wire, | Bridgeport Brass Co., Conn., | ·083 | 301* | . . | 1·4 | . . |
| | Hard drawn copper wire, | Bridgeport Brass Co., Conn , | ·083 | 305* | 303· | 1·2 | 1·3 |
| No. 8, F B B | Iron telegraph wire, | Washburn & Moen Mfg. Co., Worcester, Mass., (1) | ·157 | 1225 | . . | 10·1 | . . |
| | Iron telegraph wire, | Washburn & Moen Mfg. Co., Worcester, Mass., (1) | ·157 | 1236 | 1230·5 | 11· | 10·55 |
| No. 8, F B B | Iron telegraph wire, | Washburn & Moen Mfg. Co., Worcester, Mass., (2) | ·158 | 1224 | . . | 11·9 | . . |
| | Iron telegraph wire, | Washburn & Moen Mfg. Co., Worcester, Mass., (2) | ·158 | 1230 | 1227· | 12· | 11·95 |
| No. 14, | Hard drawn copper telegraph wire, | Washburn & Moen Mfg. Co., Worcester, Mass., (1) | ·084 | 325 | . . | ·52 | . . |
| | Hard drawn copper telegraph wire, | Washburn & Moen Mfg. Co., Worcester, Mass., (1) | ·084 | 329 | 327· | ·52 | ·52 |
| No. 14, | Hard drawn copper telegraph wire, | Washburn & Moen Mfg. Co., Worcester, Mass., (2) | ·084 | 349 | . . | ·26 | . . |
| | Hard drawn copper telegraph wire, | Washburn & Moen Mfg. Co., Worcester, Mass , (2) | ·084 | 344 | 346·5 | ·24 | ·25 |
| No. 14, B W G | Soft drawn copper telegraph wire, | Washburn & Moen Mfg. Co., Worcester, Mass , (1) | ·083 | 205 | . . | 29·7 | . . |
| | Soft drawn copper telegraph wire, | Washburn & Moen Mfg. Co., Worcester, Mass , (1) | ·083 | 206 | 205·5 | 30·2 | 29·95 |
| No. 14, B W G | Soft drawn copper telegraph wire, | Washburn & Moen Mfg. Co., Worcester, Mass., (2) | ·082 | 204 | . . | 28·1 | . . |
| | Soft drawn copper telegraph wire, | Washburn & Moen Mfg. Co., Worcester, Mass., (2) | ·082 | 204 | 204· | 31·7 | 29·9 |

* These pieces were taken from a coil which had been used as a conductor during the tests at the Electrical Exhibition.

Two specimens taken from each coil.

Yours respectfully,

JAMES W. GRANT.